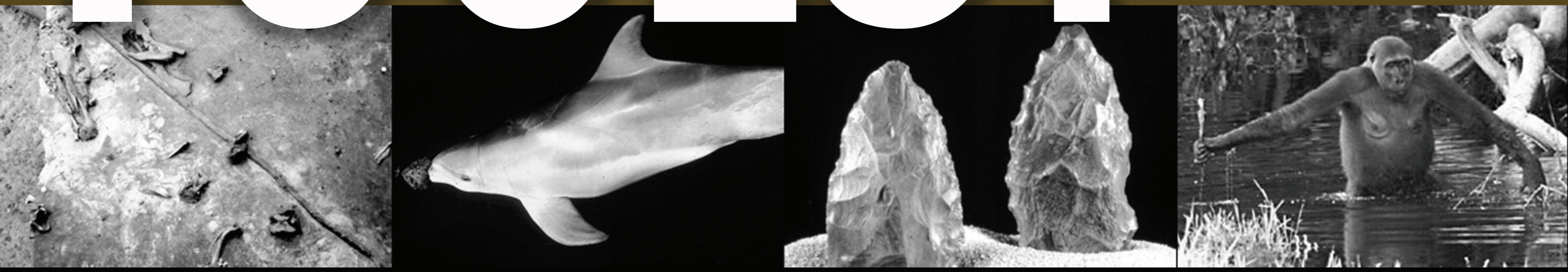
HOW TO THINK TOOLS?



a comparison of cognitive aspects in tool behavior
of animals and during human evolution.

**cognitive perspectives
in tool behaviour.**

VOL. 1

miriam noël haidle

Bibliographische Information der Deutschen Bibliothek
Die Deutsche Bibliothek verzeichnet diese Publikation in
der Deutschen Nationalbibliographie. Detaillierte bibliographische
Daten sind im Internet über
http://dnb.ddb.de abrufbar.

Bitte zitieren Sie dieses Dokument als:
urn:nbn:de:bsz:21-opus-60146
ISBN: 978-3-00-036638-3

Redaktion und Satz dieses Bandes: Regine Stolarczyk
Layout: Miriam Noël Haidle und Regine Stolarczyk
Titelseite: unit eins, www.unit-eins.de

miriam.haidle@uni-tuebingen.de
Eberhard Karls Universität Tübingen
Rümelinstr.23
72070 Tübingen

Series Preface

“Cognitive perspectives in tool behavior” is a series of volumes dealing with tool behavior in animals, fossil hominins and modern *Homo sapiens*. The papers of this series focus on cognition, but may use data of different origins and various approaches – from archaeology, paleoanthropology, primatology ethology, technology, psychology, neurology, or philosophy. Tool behavior is not exclusively human, but its development plays an important role in human evolution; today humans live in a permanent symbiosis with tools. Material manifestations of tool behavior make up the major part of the archaeological record. They are invaluable evidence not only of past people’s actions, but also of their perceptions, thoughts, cultural performances as well as cultural capacities. The aim of the series is to broaden our understanding of tool behavior in all hominin and non-human species, its different manifestations, and the corresponding cognitive prerequisites. With the collection of data and approaches from various disciplines, the “cognitive perspectives in tool behavior” will help us learn more about an important part of human behavior, gain better insights into cognitive constraints, and set them into an evolutionary frame.

“Cognitive perspectives in tool behavior” is published electronically as an open source series on the tobias-lib server of the University of Tübingen library. The volumes are accessible worldwide and can be downloaded for free as pdfs. The intention is to spread academic theses and studies with comprehensive documentation, which would otherwise not be published, would be very limited in distribution and/or very expensive to access.

The series starts with the habilitation thesis of Miriam Noël Haidle on “How to think tools? A comparison of cognitive aspects in tool behavior of animals and during human evolution”. Future volumes will include “Das Werkzeugverhalten von Schimpansen. Kognitive Flexibilität, Variabilität und Komplexität” (“Tool behavior of chimpanzees. Cognitive flexibility, variability, and complexity”) by Regine Stolarczyk and “Das Werkzeugverhalten von Orang-Utans. Kognitive Variabilität, Flexibilität und Komplexität” (“Tool behavior of orang-utans. Cognitive variability, flexibility, and complexity”) by Julia Schuster. Volumes in languages other than English include an extended English summary.

Author's Preface

The basis of this volume is my habilitation thesis from 2006. It took quite a long time and very dedicated translators (Susanne Wilhelm/Archaeoplan and Dr. Iris Trautmann/ A und O - Anthropologie und Osteoarchäologie) to translate the text into English. A further delay of publication was caused by the necessity to set up the publishing platform "Cognitive perspectives in tool behavior" on tobias-lib with the University of Tübingen library .

The study presented here represents the state of references up until 2006. In the meantime, important work has been published on the evolution of human cognition (e.g. the theme issue "The sapient mind: archaeology meets neuroscience" of the Philosophical Transactions of the Royal Society of London B 363 (2008) edited by Colin Renfrew, Chris Frith and Lambros Malafouris, and the proceedings of the Wenner Gren Symposium "Working memory: beyond language and symbolism" in Current Anthropology 51/S1 (2010) edited by Thomas Wynn and Frederick Coolidge) as well as on animal and hominin tool behaviour, which has not been included in this volume. Although this volume is partially outdated, it is nevertheless important to publish because

- it introduces new theoretical and methodological approaches to cognitive aspects in tool behavior,
- it is the basis of further studies using the problem-solution distance as a cognitive marker and cognigrams, or effective chains as methods for assessment and comparison of this cognitive aspect in tool behavior (Haidle 2009, 2010, Haidle & Bräuer 2011, Lombard & Haidle in press, Schuster 2009, Stolarczyk 2009),
- it provides a comprehensive compilation of data about animal tool behavior up to 2006,
- and it presents comparisons of tool behavior in animals and in human evolution not published elsewhere.

The underlying research was financially made possible by a position at the University of Tübingen funded by the Margarete von Wrangell program of the State of Baden-Wurttemberg 2001-2004, a follow-up position as assistant professor at the University of Tübingen, and a Feodor Lynen scholarship of the Alexander von Humboldt Foundation at the Institut for Antropologi, Arkæologi og Lingvistik, Afdeling for Forhistorisk Arkæologi of the University of Århus, Moesgård, Denmark. A number of colleagues, friends, and family members supported the work with critical questions, discussions, proof reading, and confidence. The work is dedicated to my partner Jürgen Bräuer and my Danish family Berit Eriksen and Normann Nielsen who always believed in the project and spent months focusing on the microscopic details. Any remaining problematic parts are only due to the fact that I didn't listen carefully.

Haidle, Miriam Noël 2009. How to think a simple spear? In de Beaune, Sophie A., Frederick L. Coolidge & Thomas Wynn (eds.), Cognitive archaeology and human evolution. New York: Cambridge University Press, 57-73.

Haidle, Miriam Noël 2010. Working memory capacity and the evolution of modern cognitive capacities - implications from animal and early human tool use. Current Anthropology 51/S1, S149-S166.

Haidle, Miriam Noël & Jürgen Bräuer 2011. Special Issue: Innovation and the Evolution of Human Behavior. From brainwave to tradition – How to detect innovations in tool behaviour. PaleoAnthropology 2011, 144-153.

Lombard, Marlize & Miriam Noël Haidle accepted. Thinking a bow-and-arrow: cognitive implications of Middle Stone Age bow and stone-tipped arrow technology. Cambridge Journal of Archaeology.

Schuster, Julia 2009. Das Werkzeugverhalten von Orang-Utans. Kognitive Variabilität, Flexibilität und Komplexität. MA thesis, Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, University of Tübingen (to be published in this series).

Stolarczyk, Regine 2009. Das Werkzeugverhalten von Schimpansen. Kognitive Flexibilität, Variabilität und Komplexität. MA thesis, Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, University of Tübingen (to be published in this series).

Table of Content

Series Preface 1

Author's Preface 2

Tabel of content 4

Prolog 9

I Basic Principles 12

1 Introduction 12

2 Humans: A Matter of Definition 16

3 Primates as Cognitive Approximation 22

Studies on Primates in Captivity 22

Field Research on Primates in the Wild 25

Tool Use and Tool Manufacture 25

Capacity for Culture 28

Communication and Capacity for Language 30

Different modes of learning 33

Primates as Basis for Understanding Human Cognition 35

4 Cognition: A Matter of Definition 37

II The Evolution of Human Thinking 41

5 The Evolution of Human Thinking as Phylogenetic Problem: Epistemological Background 41

Konrad Lorenz: Essay of a Natural History of Human Cognition 42

Evolutionary Epistemology – The End of Philosophical Epistemology? 45

6 The Evolution of Human Thinking as Phylogenetic Problem: Anatomical, Neuropsychological and Genetic Basics 47

Increase in Brain Size 47

Encephalization Quotient 50

Energy for Brain Growth 57

Anatomy of the Brain and Neuropsychology 58

A Genetic Foundation of Language? 63

The Regulator Hypothesis: Increased Gene Activity in the Human Brain 63

7 The Evolution of Human Thinking between Phylogeny and Individual History: The Organization of Thought 65

Language as a Mental "Organ" 65

Multiple Intelligences 67

Cognition as a Set of Highly Specialized Adaptations 69

Language as the Foundation of Human Cognition? 72

Consciousness as Executive Central Authority 75

8 The Evolution of Human Thinking as an Ontogenetic Problem 81

9 The Third Dimension: The Evolution of Human Thinking as Historical Problem 85

Cumulative Cultural Evolution through Cultural Learning 85

The Domestication of Being 90

10 Humans – Thinking – Objects 93

III The Search for Cognition in Archaeological Remains 101

11 How to Extract Thinking from Artifacts 101

Searching for Objective Universalities: Processual Archaeology 102

Cognitive Influences: Structural Approaches and Postprocessual Archaeology 102

A Melting Pot of Cognitive Approaches: Anglo-American Cognitive Archaeology 104

From Theory to Practice in Cognitive Archaeology 106

The French Way: The Technological Concept of chaînes opératoires and the schéma conceptuel 108

12 Models for the Evolution of Human Thinking Supported by Archaeology 111

The Palaeontology of Human Thinking 111

Piaget's Stage Model of the Evolution of Intelligence in the Archaeological Context 115

Depth of Planning, Projection, and Organized Action 118

From Specialized Domains of Intelligence to the Permeability of the Mind 121

Milestones: Language and Symbol Behavior 125

The Frontal Lobe – Home of Modernity 128

The "Dawn of Human Culture" as Genetic Lightning Strike 129

The Perception of Universal Divine Origin 132

13 Problems in the Approaches of Archaeological Models of Cognitive Evolution 135

The Ontogenetic Adult Perspective 137

Approaches to Artifact Categories vs. Attribute Analysis 139

IV The Increasing Distance Between Problem and Solution 143

14 Tools – A Matter of Definition 144

Tool or Toy? 148

15 Comparative Studies of Human and Animal Object Behavior 151

16 The Study of Problem-Solution-Distance: Basics 155

The Database 157

The Method: Cognigrams 159

17 Animal Tool Behavior 165

Invertebrates 165

Fishes 166

Birds 167

Mammals (other than Primates) 168

New World Monkeys 169

Old World Monkeys 170

Apes 172

Requisite Conditions 178

18 Problem-Solution Distances in Animal Tool Behavior 184

Proto-Tool Use: e.g. The Drosselschmiede 184

Tool Use and Intention: e.g. the Ant Lion 187

The Controlled Use of Tools: e.g. Baiting … 190

... And Antler Adornments in Deer 192

From Toy to Tool: Two Uses for a Feed Basket 194

Production of Tools: e.g. Leaves as Scoop and Sponge 196

Tools for a Secondary Goal: e.g. Nose Protection 197

Tools for a Higher Goal: e.g. The Cleaning Probe for Children 199

Multifunctional Tools: e.g. the Stick 201

A Neesia Fruit is not an Insect Nest: e.g. Types of Probes 203

One Tool for Multiple Subjects: e.g. Playing Catch 208

A Complete Toolbox: e.g. Extraction Sets 211

Variations and Limits 216

19 Problem-Solution Distances in Human Tool Behavior 219
Multiple Tool Elements Together: From Stacking Boxes to Assembling a Fishing Rod 219
A New Tool Function: Tools to Produce Tools 223
Secondary Tools: Exclusively Human? 227
Not Just Stone Tools: e.g. Digging Sticks for Termite Hills 232
Interruption of a Chain of Action: e.g. Transport of Raw Materials 237
About the Maintenance of Tools: e.g. Use of Fire 241
Feedback in the Thought and Action Chain: e.g. the Handaxe 247
Small Steps Away from the Acute Need: The Beginning of Human Problem-Solution Behavior 256
20 Decoupling of Tool and Need 259
Living Tools: e.g. the Spear 259
New Needs: e.g. Aesthetic Behavior 267
Combining Tool Elements: e.g. Hafting 273
21 Outlook: Of Tools and Humans, Of Innovations and Traditions 279

Appendix I Animal Tool Behaviour 288

Appendix II Early Lower Paleolithic Find Sites of the Oldowan Techno-complex 351

References 358

Prolog

The group wakes in the trees. Its members stretch and yawn. The night before, the sleeping nests were quickly prepared by twisting together subtle branches and adding some soft leaves for padding. Each animal, with the exception of the mothers and their infants, slept alone in their nest, which are now abandoned. Some leaves serve as the first meal of the day, while others gather the last over-ripe fruits from a small tree and eat them. The group slowly gathers on the forest floor and leisurely strolls away. As they roam, the animals meander in loose groups. Once in a while they gather around an abundant fruit tree. When they reach the river, the thirsty individuals bend down to drink the water. The group rests in a nearby clearing. A young female sits behind a reclining older male and uses her nimble fingers to louse his side. Two young individuals are romping about while another young individual climbs a low branch to watch them. A young male of lower status noisily tears leaves from a branch. It tries to attract the attention of the others. A female breathes heavily through her stuffed nose. She plucks a blade of grass and tickles herself until she sneezes. Around midday, the group becomes restless and hungry and moves on towards the Pandanut trees. The group has been coming here for years. Broken nut shells are scattered among anvil and hammer stones that were left here, underneath the tree, from the last visit. Older females begin cracking the very nutritious nuts while the smaller individuals watch. Older children take stones and nuts and practice cracking the nuts, which seldom works. An older male rubs his back against a tree trunk. When darkness falls, the members of the group gather near a group of loosely-spaced trees. The sleeping nests from that morning are forgotten, it’s time to build new ones …

After the family gets up in the morning, the bedding is fluffed up and stowed away for the day. While the young woman is brushing her teeth she looks into the mirror and notices the dust and chalk stains on the counter. It needs to be cleaned with vinegar cleaner. The man heats water in the boiler in the kitchen to prepare tea. He adds milk from the refrigerator to the tea in his ceramic cup. He fills a bowl with cereals and a fruit yogurt, the small child spreads the content across the kitchen table with his spoon. The smoked ham tastes even more intense on a piece of warm buttered toast. After rinsing plates and silverware, the family pulls on their jackets and grabs their bags. Outside on the steps, the man remembers that he forgot his umbrella and needs to take out the trash. The bus driver impatiently waits for the stragglers, who present their bus tickets. At the day nanny’s house, the child plays with cars and has already forgotten its parents. The woman buys a kilo of a new kind of apple at the market. The old market woman wraps the salad in newspaper. In the office, the woman opens the window, sorts her mail and blows her nose with a fresh tissue. She turns on the computer. A note on the wall reminds her to buy some flowers for a friend, who invited them over for dinner for that evening. But first, she has to prepare the tuna salad, change her clothes, get her child ready and put on her mascara. She glances at the clock just as the man opens the door with his key. Thanks to the car, they arrive just in time. After dinner they play a game with the children and drink a glass of wine. Back home, they prepare the beds for the night. He forgot to call his parents today …

I Basic Principles

1 Introduction

Objects define our (modern) humanity. They surround us day and night and are available for action. As tools, they extend our corporal abilities and act as expressions of our cognitive capabilities. They are devised and manufactured; we use them all the time. We search for new objects that solve existing problems or create unforeseen needs. Objects define the modern professional life: industry and craftsmen produce them, trade distributes them, services use them, administrations could not function without them, artists and scientists create them. And objects define daily life: tooth brushes, spatulas, shopping bags, toilet paper, pencils, photographs, cough drops, potted plants, computers, plastic dinosaurs, books, cell phones, boxes, candles, extension cords, socks, shells as souvenirs…. Objects make up our world.

Objects are naturally occurring items or artificially made artifacts that subjects – humans and animals – act with. They serve as tools in the widest sense: they are used to do something. As part of an activity they are the material expressions of cogitation, especially the ability to think outside the box. The making and use of objects is always tied to a goal that cannot be achieved directly, but only by means of a medium: the need for enhancement of individual faculties is perceived, and an object – not just any, but one that fits the challenge – is found or devised to answer the problem, as in the case of a chimpanzee child that is not allowed to touch its newborn sibling and instead uses a twig to prod it and pick up its scent from the twig. Object or tool behavior is a particular aspect of behavior that is based on causal connections and – at least partially – considerations thereof.

Although the use of tools in the animal kingdom is widespread, it is by no means universal. Only certain species of snails use stones as counterweights to righten themselves, only a few birds, like the Woodpecker Finch, search for thorns and trim them in order to dislodge insects from inaccessible knotholes. California sea otters use stones to chip abalone off the ocean floor and then to open them; they also use kelp to anchor themselves while they rest. Other objects are not employed in their natural habitat. Orangutans and chimpanzees fashion suitable objects to solve certain problems, like a sponge made of leaves to soak up water that would be difficult to access otherwise, and then transfer this solution to other applicable tasks, like bodily hygiene or the wiping up of tasty leftovers. They possess group-specific tool inventories for play, hygiene, food acquisition and intimidation display, and thus approximate human object behavior. Contemporary human behavior – whether in an industrialized Western European society or among hunter-gatherers in the south of Thailand – is characterized by the constant use of objects or tools. The solution of common problems and challenges, and, in extension, human life, without the presence and aid of utensils is inconceivable. Humans are intrinsically linked to objects.

Physical features like bipedalism, significantly reduced body hair in combination with numerous perspiratory glands, a very large brain in relation to overall body weight, and hands with opposable thumbs capable of a powerful precision grip all allow for a biological-taxonomic differentiation of humans from the average representative of other contemporary species. Manifestations of intellectual particularities like language, art, religion, and highly differentiated social behavior facilitate a more precise perception of the special nature of humans. The distinct use of objects demonstrates their peculiar integration into the environment: not only living in it, but creating their own world. With the aid of instruments, humans enable themselves to solve problems that they could not solve by their individual capabilities alone. Humanity is not characterized by physical and intellectual traits alone, but only becomes comprehensible through its unbreakable bond to inanimate objects, which through use become part of actions and thus of the human world. The connection between the consciously acting human subject and an object is established by means of cognitive processes, where the object, as a tool, becomes a temporally limited extension of the subject. Before they can be used, however, objects have to be separated from their natural environment and perceived as possible implements: a twig ceases to be just another part of a bush, but instead becomes, as opposed to other twigs, a suitable raw material to fashion a termite fishing device.

The rudiments of this intensive tool behavior already exist in chimpanzees and orangutans, who are closely related to humans, but the symbiosis with objects, so typical of modern humans, constitutes a species-specific cognitive feature. The evolution of tool behavior is therefore an excellent approach to a deeper understanding of human cognition, since not only basic elements shared with other species can be compared, but also typically human characteristics. Unlike language, art and religion, which as expressions of human cognition seem to appear out of the blue, tool behavior allows the study of similarities and differences to determine the character and degree of distinctiveness of this aspect of cognition in humans.

In addition, tool behavior has left manifold traces in form of stone tools, wooden artifacts, pottery shards and metal implements. The artifact inventories of earlier human populations constitute direct attestations of the development of this part of human thinking (fig. 1).

Yet, even the earliest stone tools and bone splinters used provide direct evidence of the perception of useable objects in the environment and the mode of extension of individual capabilities. Every archaeological site provides new artifacts to be used as primary sources, which in turn assert, challenge or add to previous studies in the development of thinking with objects. So far, archaeological finds from a time range of 2.5 million years allow the reconstruction of changes in the use and production of objects and their comparison to tools used by modern humans and animals. Therefore, both objects and object behavior hold a key position in the study of human cognitive evolution, not only because of their potential significance, but also because of their abundance as a source.

Fig. 1 The development of human object thinking, as illustrated by a series of toy figurines (Bullyland 1999). From left to right: Australopithecus with stick, *Homo habilis* with stone tool and bone, *Homo erectus* in loincloth with hand-axe and fire, Neanderthal with fur boots and clothing, mammoth tusk and a knife at his belt, and modern human with elaboratly sewn clothing, jewellery, knife and complex tools in form of spear and atlatl (spear thrower).

Human cognition is reflected in many characteristics and there are, accordingly, many different scientific disciplines that explore it. The concepts behind the fundamental notions of *human* and *cognition* are equally varied, which is why this first part on basic principles is designed to provide an overview of approaches to, as well as a framework of definitions of, the subject.

The second part deals with previous studies on the evolution of human cognition. Evolutionary epistemology, neuroanatomy and genetics constitute the phylogenetic perspective, which is primarily concerned with the biological basics of thinking. Linguistics and psychology generate models of the development of the human organization of thinking, which, apart from phylogenetic considerations, also incorporate the importance of individual, i.e. ontogenetic, development. The third dimension to be considered in the evolution of human cognition is represented by the historical and cultural potential that is studied primarily in psychology, primatology and philosophy. Finally, the second part will discuss how tool behavior can contribute to our understanding of the acquisition of cognitive capabilities and the development of the typically human cognitive space with its three dimensions of phylogeny, ontogeny and culture.

The third part explores the means previously employed to comprehend the evolution of human thinking and the cognitive background to object behavior on the basis of archaeological artifacts. It starts with an excursion into the history of archaeological theory and then proceeds to discuss, by means of eight models, the potential and limitations of archaeological approaches to the study of the development of the human mind.

The fourth part consists of a detailed study of the progressive development of human thinking, and expands to incorporate problem-solution-distance as a neutral, species and period independent basis of analysis, which applies to animal as well as human tool behavior. Following its discussion and the definition of the concept *tool*, as used in this study, is a short review of previous comparative studies on animal and human tool behavior. Then the database, containing an almost complete survey of tool usage in animals, is presented as the basis of the comparative study on problem-solution-distance, and the method of breaking down the problem-solution-distance is explained with the help of thinking-process charts. Following a general survey of animal tool behavior, various action chains in animal behavior are instanced. Numerous archaeological examples, broken down in a similar fashion, then help to understand the further development of problem-solution-distance as one aspect of human cognitive evolution.

The concluding discussion delves further into the question of which mechanisms drive and influence the development of tool behavior, the problem-solution-distance in particular, and the underlying planning capability. The synopsis of conclusions from this study offers a re-interpretation of the seemingly slow progress of tool development during the Old and Middle Palaeolithic and the “explosive” expansion of tool inventories at the start of the Late Palaeolithic, when modern humans appeared 40.000 years before present. Biological as well as cultural factors are responsible for the exponential increase of object behavior, which under close scrutiny can already be detected in the early phases of human cultural development and which continues to increase after the appearance of modern man.

2 Humans: A Matter of Definition

The discussion of the evolution of human thinking is awash with discrepancies between different approaches, due to the wide range of topics studied and unresolved questions about their interrelation. The first ambiguous point in the debate of human cognitive evolution concerns the central object of study itself: humans. The question "What is a human being?" already troubled ancient philosophers. Plato defined humans as bipedal beings without wings featuring wide, flat hand- and toenails (Becker 1993: 7). He employed a few anatomical features to distinguish average humans from average representatives of other living species known to him. Other combinations of physical features can be used to classify modern humans: the almost complete absence of body hair, the prominent chin and the vertical forehead, the generalized upper limbs represented by hands with pronounced fine motor skills, the distinctive shape of the foot resulting from bipedalism, and many more. However, these anatomical-morphological features fall short of explaining the essence of being human.

The Dutch anatomist Louis Bolk chose a physiological approach to explain the "quintessence of man as an organism" (Bolk 1926: 4). He did not see hairlessness, loss of pigmentation, the recessed face below the cranial vault, the shape of the pelvis and the position of the foramen magnum caused by upright locomotion, the substantial weight of the brain, the shape of hands and feet, and the more ventral position of the female genitalia as primary physiological features of humans, but as enduring fetal conditions, typical for primates. For Bolk, the essence of humans lay in the slow progress of development during individual life, with a markedly prolonged childhood and adolescence and an equally emphasized post-reproductive stage. He explained the fetalization of shape as the result of the hormonally triggered retardation of development (*ibid.*: 11–13). Bolk deduced the extended growth phase during childhood not only through comparison of modern humans and primates, but also from his research into the second dentition in Neanderthals (*ibid.*: 20). Contemporary palaeoanthropological studies increasingly confirm a retardation of life stages. Both the postnatal development of the brain in *Homo erectus* (Coqueugniot et al. 2004) and the odontogenesis in *Homo erectus, Homo antecessor, Homo heidelbergensis* and Neanderthals (Dean et al. 2001; MoggiCecchi 2001; Kelley 2004; Ramirez Rozzi & Bermudez de Castro 2004) indicate a significantly accelerated maturation in comparison to modern humans. Additionally, a prolonged life span after the menopause as early as in *Homo erectus* is currently under discussion (O'Connell 1999).

A third category of characteristics, besides anatomical and physiological aspects, tries to detect the essence of typical human existence within human behavior and its underlying intellectual attributes. Already Aristotle did not classify humans through physical characteristics, but saw them as *zoon logon echo*: the being that possesses language. More encompassing and remarkably vague is the view of ethologist Irenäus Eibl-Eibesfeldt (1995: 822), who cites a whole array of characteristics, but marks none as sufficiently distinctive. He describes humans as political, talking, artistically creative, tool using, thinking, rational, playing, anticipatory and cosmopolitan beings, whose curiosity remains in evidence far beyond its usual stage during infancy and adolescence, as in other animals.

Tool use, tool manufacture, visual arts, music, science, and the domestication of plants and animals are for the greater part not exclusive but typical aspects of human behavior. Karl Jaspers adds philosophy as a further "characteristic trait of man" (1997: 124), and conceives being human as "freedom … and transcendence" (*ibid.*: 57). Another typical trait of modern humans is their extraordinary adaptation for culture. Paul Alsberg pushes this argument to the extreme by viewing the human evolutionary principle of "elimination of the body" in contrast to the physical adaptation in animals, thereby inferring the absolute exceptional position of humans and placing them in their own world, apart from the world of plants and animals (1922: 426). He finds evidence for the elimination of the body in tool production, and regards the ability to make fire as a conclusive distinction between humans and animals (*ibid.:* 281). Whether the human mind or one of the characteristics rooted therein fully justify an exceptional position of humans, or whether one follows Max Verworn (1915: 34), who stated that "all intellectual evolution … exclusively [consists of] an ever detailed definition of the associative life under the selective factor of experience, and the current product of this evolutionary process is our modern intellectual culture," is still as much under dispute today as it was at the beginning of the twentieth century (see Müller-Karpe 2001a; 2001b; 2001c; Müller-Karpe et al. 2005).

It is only in combination with language and distinctive tool behavior that the human adaptation for culture creates the "freedom" emphasized by Jaspers in terms of a greatly enlarged sphere of action. The expanded ability for action becomes apparent in the extended attachment of value and the subsequently enhanced detection of problems, the creation of a distinct world, the increasing temporality of human life owing to an extended access to the past by means of the memory, and the extension of plans for the future. Together with the diversity of human life circumstances it affects the multifaceted expressions of behavior.

Humans employ very varied sustenance strategies, ranging from meat-rich to exclusively vegetarian diets. To this day, hunter-gatherer lifeways exist alongside transhumant herders, simple agrarian and artisanal societies, and industrialized economies. Human social behavior is very complex: humans live in nuclear or extended families, are patriarchically or matriarchically organized, trace their descent through their mother or their father, and maintain various political systems. Their diverse methods of communication culminate in "language," which allows for the transmission of complex events, as well as individual desires, elaborate lies, plans for the future, utopian dreams and fantastic ideas — often exclusively mental constructs. Languages are as affected by culture as the artifactual equipment of, for example, a traditional Massai or a Swedish farmer. Whereas capacity for culture in other species is uncommon or only rarely observed and always controversial, humans are very malleable in terms of cultural influences, for example through teaching. Additional characteristics of all humans living today are intellectual culture constructs, such as religion, fine arts, music and poetry. Apart from abstract, planning and reflexive thinking, which also exists in animals to a greater or lesser degree, it is symbolic thinking, i.e. the mental creation of representations, that forms the necessary basis for the development of these exclusively human intellectual systems.

All typically human characteristics and behaviors mentioned so far refer to the modern representatives of our species. However, already the concept of *modern* humans is highly variable. In relation to present-day contexts, it describes an individual that is part of the individualized and computerized knowledge-based society which emerged during the twentieth century. In an anthropological context, which comprises all contemporary forms of human existence and distinguishes them from earlier forms, “modern humans” represent anatomically modern human beings that can be traced as far back as the upper Pleistocene; their behavior shows a complexity at least equal to the minimum potential observed in subrecent groups. Anatomically modern humans, as defined by their skeletal structure (see Lieberman et al. 2002), are attested through skeletal finds for at least 100,000 years — or even ca. 160,000 years, if predecessors like *Homo sapiens idaltu* from Herto, Ethiopia, are included (White et al. 2003). Artistic-religious expressions and the use of symbols, which do not occur until later and are observable from ca. 35,000 years before present in different areas of the earth, are often quoted as markers of mental modernity (e.g., Klein 1995; Mithen 1996; Otte 2001: 91–97).

However, the beginnings of modern humans are not uncontested (see Brooks & McBrearty 2000; Balter 2002; D'Errico 2003; Henshilwood & Marrean 2004; Mellars 2005). Although it is generally assumed that the creators of the first undisputed art and jewelry during the early Upper Palaeolithic were anatomically modern humans, there are several factors that challenge their exclusively *Homo sapiens sapiens* provenance. The use of pigments and simple jewelry, such as notched and perforated teeth, are known from indisputably Middle Palaeolithic, and thus probably Neanderthal, contexts (e.g., White 2001). Likewise, bone tools as indicators of modern behavior increasingly occur already during the late Middle Palaeolithic (D'Errico et al. 1998; D'Errico 2003). Additionally, the previously postulated hiatus in stone tool technology between the late Middle Palaeolithic and the very early Upper Palaeolithic, or Aurignacien, where the earliest art appears, seems to be vanishing (see Teyssandier 2004). Furthermore, there are no undisputedly anatomically modern fossil finds in central Europe that can be dated without doubt to older than 31,000 years before present and are associated with early Upper Palaeolithic artifacts (Henri-Gambier et al. 2004; Wild et al. 2005). Thus, the oldest anatomically modern human bones in Europe, from the Peştera cu Oase cave in Romania, which date to ca. 35,000 BP, are so far not associated with any archaeological finds (Trinkaus et al. 2003). The redating of older skeletal finds like the Vogelherd individual Stetten I from previously estimated 32,000 years to the post-glacial periods (Conard et al. 2004; see alsoTerberger et al. 2001; Wild et al. 2005), in association with dating problems concerning the early Upper Palaeolithic strata (Richter et al. 2000; Conard & Bolus 2003), further fogs the issue to the extent that the exclusively *Homo sapiens sapiens* origin of Aurignacien innovations has changed in status from conclusively proven fact (Mellars 2005) to one well-founded hypothesis among others (D'Errico 2003). Another pivotal problem lies in the evaluation of prehistorical behavior, which is dependent on the researcher's position: a lot of findings from the time of several tens of thousands to million years ago are highly fragmentary and open to different interpretations. Which archaeologically detectable characteristics are necessary to define a human being? Which feature of a characteristic suffices for a classification as human? And is what we find archaeologically yet enough to detect this characteristic feature?

For example, when the use of symbols is taken as a characteristic of modernity, the question to be answered is: At what point do decorations have to be considered symbols, and when do artifacts not necessary for immediate subsistence become art? Do the ca. 35,000 year-old radial and almost rectangular carvings on bones from Bilzingsleben (Mania & Mania 1988; 1999; Steguweit 2003) qualify as symbolism? Does the reworking of arm- and neck-lines on a chunk of tuff from Berekhat Ram / Golan that naturally resembles a rough female shape constitute 280,000 year-old artistic behavior? Do the decorations on pieces of pigments or the perforated snail shells from 75,000 year-old strata at Blombos Cave, South Africa, represent any symbolical meaning? Or is it not until the magnificent naturalistic representations of animals from the glacial period between 35,000 and 30,000 years before present — in sculptures like the ivories from the Swabian Jura (Holdermann et al. 2001; Conard 2003) and wall paintings from the Grotte Chauvet (Lorblanchet 2003) — that we find the earliest evidence of symbolical thinking? Besides, the singling out of specific features like symbolism as demarcations of modernity is rather arbitrary: Would not other criteria, such as the introduction of agriculture and animal husbandry, the artificial production of new materials like metal, glass and pottery, or the use of electricity or computers be just as conceivable?

The most common definition of modern humans combines anatomical with mental modernity, which is expressed through symbolical behavior. The beginnings of this modernity are predominantly seen as originating in Europe at the onset of the Upper Palaeolithic, and it is assumed, owing to their symbolical expressiveness, that its agents possessed the same cognitive potential as present-day humans. This assumption is based on the basic equation of late Palaeolithic with modern hunter-gatherer groups and the acceptance of widely identical cognitive capabilities amongst present-day humans in general. However, whether hunting and gathering societies that are separated by up to 40,000 years of development can in fact be equated, whether the differentiation of human lifeways in the post-glacial period merely constitutes an expansion of cultural characteristics, and whether the evolution of the human genetical cognitive potential stopped sometime between 100,000–40,000 years before present, can not be proven thus far.

The definition of "modern human" considerably restricts the concept of man. For a long time biological species, including humans, were viewed as the static product of creation, their characteristics and distinctions clearly defined and segregated. However, with the advent of the evolution theory, this groundbreaking philosophical idea that emerged during the nineteenth century, their development and thus their interrelationship based on descent became a distinct possibility. The discovery of fossil human remains in the Neanderthal near Düsseldorf and their interpretation as an ancient human life-form by Johann Carl Fuhlrott and Hermann Schaafhausen, which culminated in their classification as the distinct human species *Homo neanderthalensis* (King 1864), finally opened the door to an extended concept of humans.

Nowadays, there are twenty possible fossil species clustered around anatomically modern man, classified as real humans (genus *Homo*) or hominids (subfamily *Homininae*): ten of these species alone were only discovered or classified after 1990 (fig. 2).

The group of currently known or classified fossil hominids consists of direct ancestors of modern humans, whose identification as such is difficult, and their descendants that came to evolutionary dead ends. Since the genetic relations among the classified species are mostly unresolved, the use of phylogenetic trees is more and more abandoned in favor of graphs that illustrate the probable timespan for each species as a bar (see also Wood 2002: 134). Research is mainly focused on the search for morphological forms that are, or can be interpreted as, closely associated to the evolution of anatomically modern humans, such as the recent discoveries of *Homo antecessor* (Carbonell et al. 1995), *Kenyanthropus platyops* (Leakey et al. 2001), and *Sahelanthropus tchadensis* (Brunet et al. 2002). The assignation of mental capabilities and the tracing of human cognitive evolution are hampered by inconclusive correlations between human fossils and artifacts.

There is no universal definition of humans. In 1758, when the tenth edition of "*Systema naturae"* by Carl von Linné, which forms the basis of modern taxonomic classification, was published, there existed but one representative of the human species: *Homo sapiens*; further classification and definition seemed unnecessary. Thus, the definition of humans can be applied to modern man, with all inherent problems discussed earlier, as well as a whole group of human ancestors, actually exceeding the timespan of the first appearance of the genus *Homo* ca. 2.5 million years ago. This present study takes up the extended definition of humans. Its primary aim is not the identification of absolute markers for human actions, which would allow for the clear distinction between "full-fledged humans" and primates displaying certain anatomically human traits. Such a distinction is static by definition and impedes the reconstruction of evolution (see Whiten 2005: 53). Rather, the analysis of material remains of actions, such as stone tools, wooden objects, bone, antler and ivory tools, is used to trace the development of human cognition and the resulting expanded capabilities of action, which originate from the final common ancestors of great apes (especially chimpanzees) and humans. The study of the cognitive potential of the great apes as our closest living relatives allows for – with reservations – an approximation of the intellectual potential of our common ancestors ca. 6 million years ago.

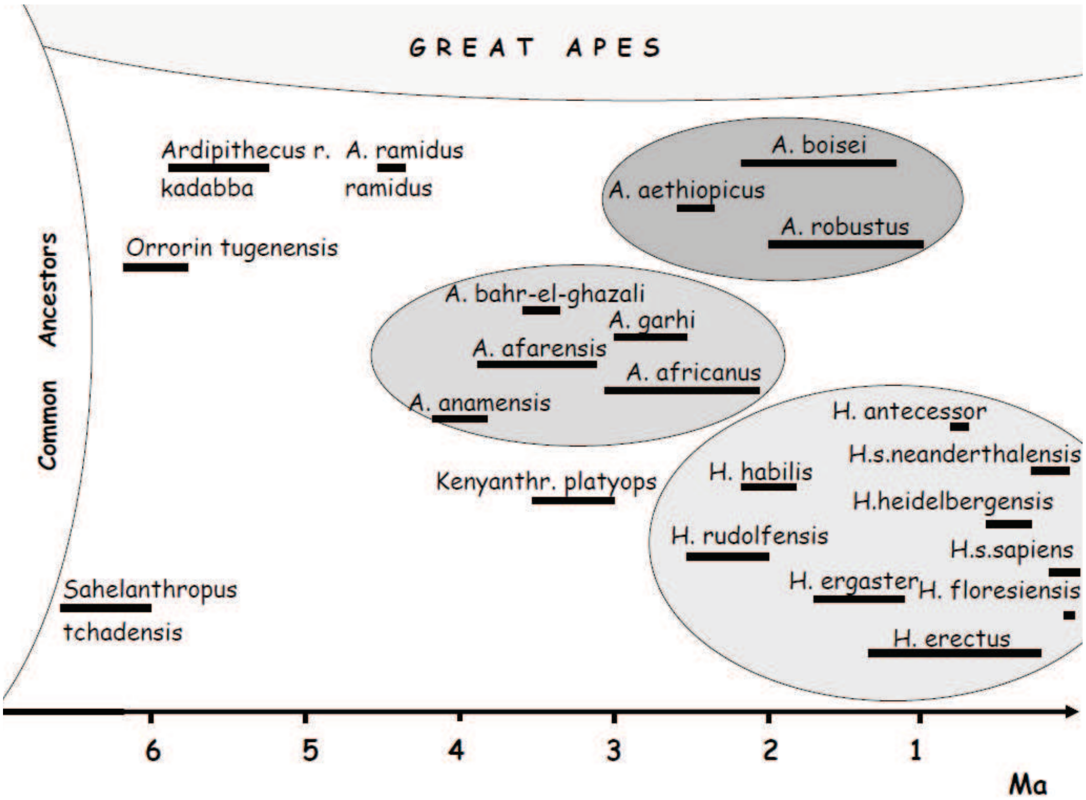


Fig. 2 Possible ancestors of modern man, *Homo sapiens sapiens*. The species under current discussion are displayed with their approximate range of dating (bar). Since the actual line of descent among the different species is unclear, only morphological groups are indicated here: gracile australopithecines as *Australopithecus afarensis*, robust australopithecines (pr paranthropines) as *Australopithecus robustus*, and representatives of the genus *Homo* as *Homo sapiens sapiens*.

3 Primates as Cognitive Approximation

Early on in the twentieth century, their close physical resemblance to humans raised the question of just how much similarity existed between the behavior and intelligence of the great apes and our own. Psychological testing of captive animals with sophisticated setups was expected to provide insight into a primal form of human intelligence (Köhler 1963: 1), although its implications for the cognitive ability of prehumans in the palaeoanthropological sense were not considered. Even today, only a minority of primate studies explicitly models the development of humans or human thinking. Yet, as our closest living relatives, primates – especially chimpanzees and bonobos – *per se* act as models of original human ecology and capabilities and their ensuing behavior (Yamakoshi 2001: 548; McGrew 1992: 62–63; e.g., Matsuzawa 2001). Questions regarding the adaptive significance of tool use in the acquisition of food, for example, can be checked through primate models (Yamakoshi 2001). The use of primate models typically proceeds on the simplified assumption that the mental capabilities of modern humans which differ from those of primates developed within the hominine branch after its split from the primate line. Possible parallel development of various cognitive characteristics, e.g., in chimpanzees and humans, after the split is not considered. Human particularities are summarily viewed as autapomorphous human characteristics, despite the lack of accurate data about the independent development of comparative species.

Although already Yerkes and Yerkes in 1929 (pp. 529–80) drew systematic analogies of behavior between the great ape species and between pongids and other apes, models of species-specific cognitive systems that incorporate the independent mental evolution of the different primate species are rare. The available amount of data for such models is – despite enormous progress during the last thirty years – still small, and this shortcoming serves the continuous equation of primate behavior with original behavior, which only perpetuates our distorted view of our common ancestor's behavior. Yet, despite these restrictions, evidence for the cognitive capacities of great apes and apes, like problemsolving and tool behavior, culture, language skills or learning, allows for at least an approximation to the origins of typically human thinking.

Studies on Primates in Captivity

There are three methods for studying animal intelligence: controlled experiments in captivity, observation of groups in captivity without specific scope, and observation of populations in the wild with or without additional provision of food. Studies in captivity offer insight into the cognitive foundations of various behavioral patterns and allow the study of behavior that would be difficult to observe in the natural habitat. Experiments are conducted under controlled conditions, so that the impact of changes in the environment can be monitored. They enable the study of long-term individual developments through repeated set-ups and an approximation to the cognitive potential of the species under study. The amount of data thus obtained can be expanded to allow statistical analysis and direct comparison of different species. At the same time, the advantages of the artificial environment in controlled experiments have to be weighed against the disadvantages of laboratory research: the constricted setting with non-species-specific challenges, the artificial stimulus through controlled environment and designated problems as well as limited possibilities of solution all compromise the significance of the results when compared to actual species-specific behavior.

Already at the beginning of the twentieth century behavioral studies of captive great apes became very popular in several countries (see Yerkes & Yerkes 1929: 582–86; Goodall 1986: 7–8). Their origins lie in private preserves like that of Mrs. Abreu in Cuba or in the primate group established in 1910 in Santa Barbara, California, by G.V. Hamilton. The latter provided Robert Yerkes with an orangutan for his first study on rational behavior in primates (Yerkes 1916); he later repeated similar studies with a juvenile female chimpanzee and a bonobo (Yerkes & Learned 1925). On Tenerife, the Prussian Academy of Sciences (Preußische Akademie der Wissenschaften) maintained a research station between 1912 and 1918, where Wolfgang Köhler (1963) studied tool use in the solution of different problems on captive chimpanzees. The department of zoopsychology at the Darwin Museum in Moscow started experiments in the intelligence of primates in 1916. After World War I, the French Institut Pasteur opened a primate station in Kindia, French Guinea, that conducted mainly medical experiments. In 1924 finally, the Department of Psychology of Yale University in New Haven, Connecticut, began building a habitat that combined outdoor observation, breeding programs and an experimental laboratoty. Long-term observations and experiments, especially on chimpanzees and gorillas, were carried out here (Yerkes & Yerkes 1929). This research facility later spawned the Yerkes Primate Laboratory in Florida and the Yerkes Regional Primate Research Center in Atlanta, Georgia. In addition to these exclusively primate studies, comparative experiments with young chimpanzees and children were also conducted early on (see Goodall 1986: 7–8; Kohts 1923; Kellog 1931).

Since the 1960s, research on primates in captivity has again reached a new high. Language learning programs with great apes have been intensified and psychological tests in the laboratory and on captive populations were systematized (see Goodall 1986: 8–9). Besides studies on problem-solving and cultural behavior, communication capabilities and various learning processes (see Nielsen et al. 2005), the best known examples of primatological studies on cognitive approaches are the mirror tests conducted by Gordon Gallup (1970; 1975). A first experiment tested the reaction of several primates to their reflection. While chimpanzees proceeded from social displays directed toward the reflection to self-directed responses with the aid of the mirror within a few days, several species of macaques hardly perceived the reflections as their own, even after weeks. In a second experiment, chimpanzees were marked with a red spot on their brow and ear while anesthesized. In absence of a mirror the chimpanzees rarely touched the mark, but when confronted with their reflection, they touched the marks on themselves repeatedly. Generally, these tests are seen as evidence that, unlike other primates, chimpanzees, orangutans (Lethmate & Drücker 1973), as well as gorillas (Patterson & Cohn 1994, cited in Byrne 1996) recognize their reflection as a portrayal of themselves, and thus possess self-awareness. However, in a critical discussion of the mirror tests Heyes (1994) questions the deduced interpretation as self-awareness and offers other and simpler cognitive explanations. Controlled and comparative studies such as those mentioned above are only possible in captivity. They allow insight into the potential and certain areas of the cognitive abilities of animals that could hardly be discovered through the observation of primate groups in the wild.

Field Research on Primates in the Wild

Studies carried out on animals in their natural environment gather data that complement the results obtained through research in captivity or the laboratory. As early as 1930, Henry Nissen initiated the first long-term field study on chimpanzees in French Guinea, which lasted two and a half months. But it is only since the 1960s that systematic long-term behavioral studies of wild populations of chimpanzees (e.g., Goodall 1986; Boesch 2000; Nishida & Hiraiwa 1982), bonobos (e.g., Kano 1992), gorillas (e.g., Fossey 1989), orangutans on Sumatra and Borneo (see Fox et al. 1999: 99), as well as macaques, baboons (e.g., Strum 1983a; 1983b) and other primates, prevailed over short-term studies, which had dominated the field until then (De Vore 1965). Today, results from different groups are increasingly connected via the formulation of distinct problems (e.g, Whiten et al. 1999; Schaik et al. 2003), in order to gain a better overview of species-specific cognitive capabilities and to be able to track differences in the ways the primate populations employ them.

Observations in the wild yield insights unobtainable in captivity, such as natural group composition, its stability and possible developments, feeding habits, and preferred environment – if not restricted by humans. Additionally, field research conveys information about the range and variety of problems perceived by different species. Group-specific differences help to detect various modes of behavior, such as traditions, and – in rare cases – enable to trace the diffusion of innovations. Natural food and object behavior points to selection criteria for food and raw materials, as well as their handling. Patterns and flexibility in the use of territory and through seasonally changing behavior are affected by the perception and the species-specific internal view of the environment. In cases where the current habitat proves insufficient to solve a specific problem, a detailed mental map of the territory faciltitates the use of opportunities within the surrounding area in a selective, and thus planned, manner (see Boesch & Boesch 1984b).

The time-consuming habituation of wild animals to humans, on the other hand, restricts the gathering of data, and the diversity of the natural environment and of the behavior limits the possibilities of analysis. After nine years of research, with an average of nine months in the field, Boesch and Boesch (1990: 87) describe these dificulties:

> *"Habituation to human observers was a slow process and only after 5 years were we able to follow by sight some of the males. We did not carry out artificial provisioning, but tried to follow the chimpanzees by their vocalizations, making visual contact whenever possible. It is at present still difficult to follow some of the timid females. Knowing the females seem to be the keenest tool users, it is not surprising that it took us years to have a fair idea of the variety of their tool use. For instance, females practise ant dipping mostly at the rear of a party and always interrupted it when we approached. We saw this behavior for the first time in autumn 1987, i.e. 8 years after observations started. Similarly, in 45 months of initial observation, Goodall saw ant dipping only once, although it is common in Gombe."*

Observations on populations in the wild are typically opportunistic and not directed towards a specific behavior; reports therefore remain largely anecdotal. Only rarely a certain type of behavior has been researched as systematically as the nut-cracking employed by the chimpanzee population in Taï National Park, Ivory Coast, where – amongst others – sex differences and the transport of raw materials could be analyzed in detail (Boesch & Boesch 1981; 1983; 1984a; 1984b). Experiments, such as those carried out on wild chimpanzees by Matsuzawa et al. (2001) in their field laboratory in Bossou, where raw materials and food are provisioned, provide an alternative approach to specific data surveys. As the particular circumstances of observation, regarding, for example, the lack or frequency of specific behavior, often vary widely, direct comparison of different groups – let alone different primate species – is difficult, if not impossible. Thus, both studies in captivity and observations in the wild only allow limited conclusions about the cognitive capabilities of primates. The combination of both approaches, however, makes it possible to trace the outline of their intellectual power, which finds its expression in tool use, capacity for culture, communication and learning ability.

Tool Use and Tool Manufacture

For a long time, the use of natural or artificially altered objects as tools has been regarded a typically human characteristic and was considered to denote "intelligent" behavior, a trait that was mostly denied to animals. Although primatological research was focused on tool use among primates from the start, its results passed largely unheeded until the 1960s. Individual casual observations of primate tool use in the wild – such as the use of hammer stones among capuchin monkeys (Gonzalo Fernandéz de Oviedo 1526 in Urbani 1998 in Ottoni & Mannu 2001), the throwing of branches at trespassers among howler monkeys (Dampier 1697; 1705 in Becker 1993), the opening of shells among macaques (Carpenter 1887), or the nut-cracking with stones among chimpanzees (Savage & Wyman 1843–44 in Beck 1980) – reach as far back as the sixteenth century, and are, as the example of Abyssinian baboons cracking the pits of fruits with the help of stones shows (Schweinfurth 1902: 302), repeatedly attested. Studies on animals in captivity equally attested early on that primates use tools and are able to reach individual solutions to problems (Yerkes 1916; Köhler 1963; Yerkes & Yerkes 1929; Guillaume & Meyerson 1930; 1931; 1934).

Already in the 1920s, Wolfgang Köhler (1963) developed a model for the cognitive interpretation of tool use and manufacture among primates, based on his experiments at the research station of the Prussian Academy of Sciences on Tenerife. He recognized tool use as an extension of the principle of thinking outside the box, that is, of achieving a goal indirectly. Simple experiments, where an object was placed behind a fence and was not accessible by direct but only indirect means, showed that such tasks could be solved by infants, chimpanzees and dogs, but not, for example, by chickens (*ibid.*: 8–10). An indirect solution, which required the use of an actual intermediate, like a piece of string by which the target object could be pulled within reach, could only be achieved by primates and humans (*ibid.*: 18). In his experiments, Köhler observed various forms of simple tool use in the solution of a problem by means of readily accessible objects (*ibid.*: 22–40). At the same time, he discerned playful interaction with objects without necessity, where earlier tool use might lead to its playful repetition, and playing around with objects could end in tool use (*ibid.*: 49). He illustrated the seamless transition between object play and tool use, but would only accept test problems of his devising as real problems. Problems perceived by the animals themselves, which led them to use sticks as levers, spoons, digging sticks, probes, weapons or missiles, to drape objects on their body as some kind of adornment, or to paint parts of their environment with clay they had moistened in their mouths, were interpreted by Köhler not as problems, but as play (*ibid.*: 50–71).

While Köhler already characterized tool use as an indirect action, the elements of which seem irrelevant to the achievement of the goal when viewed separately, but become meaningful only in context, tool manufacture to him meant a progression in the use of indirect means (*ibid.*:71–72). Not only does manufacture require the use of a material intermediate (tool), but the actual goal has to be pushed aside for a while in favor of a different goal (tool manufacture). Additionally, the task cannot be associated with any given object, e.g. a stick, but the object – the stick – has to be visually separated from the branch of a tree (*ibid.*: 75). In his experiments, Köhler was able to observe the manufacture of tools, such as the snapping off of branches, the joining of several pipes for extension, and the sharpening of tools, as well as the construction of box stacks (*ibid.*: 96–123), and problem solution by indirect means via independent intermediate solutions. In the latter experiments, the problem was unsolvable with aid of the directly available tools alone, but these tools could be used to attain an object that would lead to a solution. This combination of tool use was only achieved by the more apt test animals (*ibid.*: 124–33). Although Köhler addressed the issue of tool manufacture among chimpanzees as early as 1921, the universally accepted opinion remained that tool use was a predominantly human characteristic, while tool manufacture was exclusively so. Primates were granted perceptual thinking, while conceptional thinking was seen as typical for humans (Oakley 1963: 1–2).

Tool behavior not initiated by humans only attracted greater attention through the observations of Jane Goodall (1964) among chimpanzees (*pan troglodytes*) in Gombe, Tanzania. In the following decades, reports of tool use and manufacture among chimpanzee populations in the wild increased (e.g., Jones & Sabater Pi 1969; Nishida 1973; Sabater Pi 1974; Teleki 1974; Nishida & Hiraiwa 1982; Boesch & Boesch 1981; 1983; 1984a; 1984b; Sugiyama 1985; Goodall 1986). Long-term studies on Sumatra and Borneo finally yielded proof of complex tool behavior in orangutans (*pongo pygmaeus*) living in the wild (e.g., van Schaik et al. 1996; Fox et al. 1999; van Schaik & Knott 2001; Fox & Bin' Muhammad 2002), which for a long time had been known only from zoo animals or through experiments (e.g., Lethmate 1976a; 1976b; 1977a; 1977b). Since the spontaneous and varied tool use of pygmy chimpanzees, or bonobos (*pan paniscus*), had already been observed in captivity (Jordan 1982), it was only a matter of time before tool use could be reported from bonobo populations in the wild (Hohmann & Fruth 2003), exceeding the use of sticks for play or of leafy branches as rain shelter (McGrew 1992: 47; Ingmanson 1996). Tool use among gorillas (*gorilla gorilla*) has so far been mostly attested in captive animals (Boysen et al. 1999; Parker et al. 1999; see Appendix).

Comparisons between great ape species, as well as between great apes and other primates, have been drawn early on: Robert and Ada Yerkes (1929: 577) noticed that primates display only the most basic tool use, which is quite common among the great apes and occurs there with an additional tendency towards tool manufacture. While tool behavior among gorillas is not pronounced, not even in captivity, it is part of the common behavioral repertoire in orangutans and chimpanzees (*ibid.*: 550). However, indications of species-specific specializations in the qualitative characteristics of tool behavior are still few and far between. Unlike chimpanzees (*pan troglodytes*), who primarily use tools in the context of food acquisition, tool use among bonobos (*pan paniscus*) mainly focuses on the avoidance of physical discomfort or social interactions with members of the same species (Ingmanson 1996). So far, gorillas (*gorilla gorilla*) have only rarely been observed to exhibit tool behavior in their natural habitat, but their complex behavior in dealing with the defenses of their food plants has been noted, as well as frequent intensive observing behavior (Byrne 1996; 1999). While tufted capuchins (*cebus apella*) develop very varied tool use in captivity, their behavior during experiments is often irrelevant to the solution of the problem. Observations indicate that they lack a mental image of the probably adequate solutions, which leads to heavy experimenting with every possible alternative, even nonsensical ones. Other than the great apes, they do not seem to be able to comprehend imitation or the interaction of cause and effect (Visalberghi & Limongelli 1996).

Gen Yamakoshi (2001) believes that ecological reasons are behind the varying degrees of tool use among the great apes. In a study of several wild chimpanzee populations, he noticed that the animals mainly consume fruits, leaves, and herbs, and that tools are typically used to obtain resources that are difficult to reach, such as social insects, honey, algae, and nuts (*ibid.*: 542–43). Tool use seems to facilitate the procurement of additional food resources during the seasons when fruits are sparse. In this process, the adaptive importance of tool use is not found in the more effective exploitation of preferential seasonal food resources – as posited by Parker and Gibson (1979) – but in the circumvention of the seasonal dearth of the main food supply through the supplementation of other, harder to reach, but plentiful food resources (Yamakoshi 2001: 550). Yamakoshi attributes the lack of tool use among bonobos and gorillas to the absence of seasonal periods of dearth in their respective habitats (*ibid.*: 551).

The most important cognitive difference between humans and chimpanzees, except for language, following White (1942), Köhler (1963), Osvath and Gärdenfors (2005), amongst others, lies in their mode of thinking, which in primates is closely tied to the present, extending very little into the past or the future. Especially the limited future impairs tool manufacture: the preparation for a future goal not only requires the imagination of proper planned actions, but also the "imagination of certain *extraneous* circumstances in the near or further future" (Köhler 1963: 196). In his observations of tool manufacture among chimpanzees, Köhler noted that an actually perceivable goal facilitated the process, while the limited present interest in future rewards detracted from the manufacture of tools for future use (*ibid.*: 196–97). While the basis for actions in chimpanzees lies solely in perceptions, human actions can also be triggered by conceptions (*ibid.*: 200). Köhler identifies this lack of conceptional thinking as the main reason for the general absence of cultural development among chimpanzees (*ibid.*: 192).

Capacity for Culture

In reaction to Jane Goodall's early observations of tool-using and –manufacturing chimpanzees in the wild, which rendered the concept of "tool manufacture" as a defining human trait obsolete, Holloway (1969) proclaimed culture to belong exclusively to the human sphere. This statement, however, is strongly dependent on the definition of culture and cultural behavior. While some scholars define culture as a tradition in terms of a specific behavioral pattern that is shared by two or more individuals of a social unit, retained over a longer period of time, and transmitted to new users partly by socially assisted teaching/learning procedures (see Whiten 2005: 53), other definitions of cultural behavior are much more exclusive. Lethmate (1991: 134) distinguishes several discipline-specific culture principles, and defines culture from the viewpoint of primatology as behavior that (1) is not exclusively attributable to ecology, (2) is shared by many members of a group, (3) is handed down through generations, i.e., forming a tradition, and (4) is not transferred genetically, but socially. He finds indications of all four conditions amongst chimpanzees, although many details remain unclear to him, owing to the limited availability of data (*ibid.*: 137–38). McGrew (1992) specifically studies the material culture of chimpanzees and establishes eight criteria for cultural actions, which are partly congruent with Lethmate's. In his opinion, all of the following criteria have to be met in order to identify culture beyond doubt: innovation, social transmission to other individuals, standardization and persistence of behavior, dissemination amongst groups, tradition spanning generations, not induced by subsistence, and natural occurrence without, or only with very little, human influence (*ibid.*: 76–79). Following McGrew, no single population shows a behavioral pattern where all eight criteria are met, but they all appear individually within the context of tool behavior among chimpanzees.

Wrangham et al. (1994) collect various indications of chimpanzee culture, but only Whiten et al. (1999; 2001) succeed – by systematic comparison of seven populations studied on a long-term basis – in separating 39 behavioral patterns with cultural background from a possible pool of 65. In contrast to earlier studies, a quantification of behavior within a given group was also attempted. Customary behavior is prevalent within the population, habitual behavior can at least be observed among several important individuals on a regular basis. Other categories include rare behavior, existing behavior with unknown frequency, absent behavior due to ecological circumstances, absent behavior, and no information. The so-called geographical approach of Whiten et al. (1999; 2001) defines behavior as cultural if it occurs customarily or habitually within at least one group, but is absent in at least one other living under similar ecological circumstances. If the absence of a certain behavior can be attributed to ecological causes in each case, it is eliminated from the list of indicative cultural markers. In this way, Whiten et al. establish the basis for an ethnography of chimpanzees. Like humans, but unlike other animals, chimpanzees exhibit not only individual behavioral patterns, but whole systems of behavior that are group-specific and passed on culturally. In chimpanzees, Whiten and Boesch (2002: 38) recognize the beginnings of the cumulative cultural process that culminates in modern humans.

Motivated by the example of chimpanzees, an attempt was made to identify culturally induced behavior in orangutans. Van Schaik et al. (2003) compared six populations studied under long-term conditions on Borneo and Sumatra according to the criteria established for chimpanzees by Whiten et al. (1999). They identified 19 of the 36 studied behavioral patterns as very probable cultural variants; for a further five, ecological explanations could not be completely ruled out. Unlike in the studied chimpanzee populations, van Schaik et al. found among the orangutans a significant correlation between the geographical distance between groups and the percentage of differences of all customary or habitual local variants. This statistical relationship backs the hypothesis that innovations within individual groups are transmitted to other groups through social contact. Additionally, a significant relationship existed between the percentage of time spent in the company of independent individuals and the number of subsistence-related customary or habitual behavioral patterns. This indicates that orangutans also learn socially from other group members than just their mother. Other suspected causes of greater variation in cultural behavior, like a higher need of innovations due to less favorable ecological conditions or ample opportunity for playful exploration of the environment due to enough spare time, however, proved to be statistically not significant. Therefore, van Schaik et al. (2003: 105) conclude that “the presence in orangutans of humanlike skill (material culture) pushes back its origin in the hominoid lineage to about 14 million years ago, when orangutan and African ape clades last shared a common ancestor, rather than to the last common ancestor of chimpanzees and humans.”

Communication and Capacity for Language

The development and extensive use of language are significant characteristics of human cognition. The requirements for modern human phonetic language can be divided into three distinctive groups: the capability to communicate, language competence, and the capacity to vocalize (see Haidle 2004). Capability for communication involves the awareness of one's own motivations – “What do I want to communicate?” – as well as an awareness of the communication's context: for example, that “apple” has a different meaning than “orange,” i.e., a differentiation between categories A and B. Additionally, an awareness of possible knowledge gaps of the counterpart is required, as well as the knowledge that these gaps can be bridged. Capability for communication is an integral part of social intelligence, the development of which, during the course of human evolution, cannot be deduced directly from archaeological or fossil finds, but has to be approached via primate models. Besides the social competence for communication, an individual willing to develop language needs specific physical characteristics in order to be able to communicate. The neurological requirements for the generation, perception and comprehension of language elements, or analogous signs, are subsumed under the concept of capability for language. The primate-specific use of sign systems can be correlated with their brain anatomy and, thus, serve as a comparison for the functions of human brain areas. Vocalization, on the other hand, defines the capability to consciously produce different sounds, which is essential for spoken languages, but irrelevant for sign languages. Primate experiments on communication mainly focus on the capability for social communication, as well as the perception and comprehension of language elements, without comparisons to the anatomy of the human brain.

First experiments with spoken language were conducted by Keith and Cathy Hayes between 1947 and 1953 on the female chimpanzee Viki. In order to not only gain insight into the comprehension of language, but also to find out more about the capabilities for the use of language as a communication device and the combination of terms or simple grammatical rules, spoken language was subsequently replaced by various sign systems. Thus, laboratory animals were able to express themselves even though they were lacking vocalization skills. Allen and Beatrice Gardner (1969), for example, taught the female chimpanzee Washoe between 1966 and the end of the 1970s more than 130 signs of the American Sign Language. David and Ann Premack communicated with Sarah in an artificial language, the elements of which were composed by abstract pieces of plastic that differed in form, color, size, and surface texture. Duane Rumbaugh taught the female chimpanzee Lana Yerkish, a system of 25 symbols arranged on a computer keyboard, with which she was able to control parts of her environment, such as food, drink and entertainment through music and videos, by correctly phrasing her wishes (see Goodall 1986: 11–12).

The most impressive capability of communication through human sign systems so far was exhibited by the bonobo Kanzi. Sue Savage-Rumbaugh was working on language programs with bonobos and chimpanzees, teaching Kanzi's mother to use a computer keyboard that displayed various symbols – so-called lexigrams. While efforts with the adult bonobo mother amounted to little, her son, without being taught himself, was able to acquire –in passing and just by his mere presence during the experiments – a vocabulary of over 120 signs that were not limited to the designation of objects, but also could indicate actions and relationships. Moreover, Kanji showed the capability to deceive and to express wishes, thus using the lexigrams outside the physical context of their original meaning (Savage-Rumbaugh et al. 1986; 1993). As a result, the lexigrams can be considered "words" with a conventional link to associated thoughts (see Deacon 1994: 130). On occasion, Kanzi and other probands also combined multiple signs repeatedly in a significant manner (Savage-Rumbaugh et al. 1986; 1993).

This evidence of syntactic structures in multi-word expressions, a kind of proto-grammar, is indicative of Kanzi's capacity for language (Savage-Rumbaugh & Lewin 1998:189). Linguists consider grammar to be an essential element of language. However, following Savage-Rumbaugh and Lewin (pp. 180–81), the model of modern language structure has to be deemed inapplicable to earlier stages of development. Instead of the existence of regularities in form of grammatical rules in other stages of development, they stress the importance of the capability to invent rules in the first place. These rules, which can differ considerably from our present ones, mirror the adaptation and behavior of primates and early humans, which in turn can vary from the adaptation and behavior of modern humans. Besides the actual use of signs in communication, Rumbaugh et al. (1986) also emphasize the importance of comprehension capability. Even though an ape is not capable of speech, the capability to understand language is considered the cognitive equivalent of accomplished language acquisition. The comprehension of sounds and the breaking up of phonetic sequences are prerequisites for language production. In children, comprehension precedes active speech in the single-word as well as the sentence stage (Savage-Rumbaugh & Lewin 1998: 191–92). The singularity of comprehension lies in the decoding of the counterpart's intent. While an individual producing language knows what it thinks and wants to say, comprehension involves not only the separate perception of short phonetic groups, but also the inference of the counterpart's intention and the informative value of the message (*ibid.*: 199). To explain the existence of a certain amount of language capability in chimpanzees and bonobos without the development of a simple proper language system, as well as the evidence for the rather late appearance of language within human evolution, Savage-Rumbaugh and Lewin (pp. 277–78) postulate that the cognitive foundations of language are actually an adaptation for purposes other than language, such as, for example, the planning of future actions, the manufacture of tools, or empathy with another individual.

The analysis of laboratory experiments is complicated by the fact that, while chimpanzees and bonobos can learn to use signs in a language-like manner, the necessary constituents for these interactions are provided by fully language-capable humans. However, the tests still attest relatively advanced communication capabilities in at least some individuals. The capacity for language is also partially evidenced: the simple use of a limited set of symbols can be learned. Whether and how the development of a proper primate signs system is possible, though, has to remain an open question. Additionally, the vocalization among great apes is severly limited in comparison to humans.

Research on wild vervet monkeys discovered a species-specific vocal sign system that is based on several acoustic modes of communication (Seyfarth & Cheney 1991). On seeing predators, they vocalize different alarm calls depending on the specific kind of threat, whether eagle, leopard or snake, which trigger different and appropriate reactions from the group as a whole. When encountering another group of their own species, they react with two different vocalizations depending on whether mere presence is acknowledged or threats are issued. Several experiments proved that the alarm calls contain distinct information and, consequently, are to be considered semantic signals. Vervet monkeys showed the same reactions to calls replayed through hidden loudspeakers without the presence of predators or when the length or volume of the calls had been changed. Habituation experiments with chatter vocalizations indicate that these as well are not mere acoustic stimuli, but information carriers. The typical vocalizations, however, are innate. Their correct use – when they are to be uttered and the proper reaction to them – is learned by imitation; active transmission through positive feedback for correct calls or correction in case of improper reactions does not occur (Seyfarth & Cheney 1993: 130). In contrast to the laboratory conditions of language experiments with great apes, research on vervet monkeys in the wild provides information on the species-specific use of communication and language capabilities and on the transmission of a behavior, that is, on the form of learning characteristic to this species.

Different modes of learning

The study of learning competence and behavior originated in developmental psychology, where research with children expanded into research on primates. Experiments that compared the learning processes and capabilities of children and primates in reaction to identical stimuli were already conducted early on (e.g., Kohts 1923; Kellog 1931). Besides these attempts to trace learning behavior within the development of particular individuals, systematic studies on learning in primates were also conducted, which are closely linked to the study of tool behavior. Early research focused on the individual learning process and lead to the differentiation of trial-and-error learning, which is frequent in animals, from rational learning. First experiments on differences in the mental capacities of great apes and humans were conducted by Wolfgang Köhler (1963) on captive chimpanzees at the research station of the Prussian Academy of Sciences on Tenerife in 1914–1916. In his study on tool use in the solution of various problem situations, he found, in addition to trial-and-error learning, indications of rational considerations as the basis of tool use in chimpanzees – a point of view he shared with Robert Yerkes (Yekes & Learned 1925: 38). Köhler considered the spontaneous occurrence of coordinated proper solutions for complex tool problems, as well as the postulated animal comprehension of critical relationships, to be attributes of rational thinking. These attributes, as well as the assumption of rational thinking as an independent learning process, were later challenged, since – amongst other things – rational thinking is highly dependent on previous experiences (see Beck 1980: 158–62).

Recent research on learning in primates focuses on the modes of knowledge transmission in individual groups, which figures prominently within the discussion of cultural behavior in primates (see Beck 1980: 162–77; Sunita et al. 1985). Tomasello (2002: 37, 40–47; see chapter 9) distinguishes the following as possible learning modes for group-specific behavior: physical contact with a learning situation in the group-specific environment, increased stimulation, imitation and emulation, and learning based on the effects of behavior of other individuals without comprehension of their behavioral strategies. Additional to frequently repeated social interactions, which can lead to ritualized behavior between individuals, imitation and active teaching are further forms of knowledge transmission. Teaching among wild chimpanzees has only been observed in connection with the nut-cracking with hammer and anvil prevalent in the group from Taï National Park, Ivory Coast

(Boesch 1991). While Caro and Hauser (1992) consider all behavior that assists the learning process of another individual as teaching, Boesch and Tomasello (1998: 601) distinguish between the deliberate facilitation of learning, as occasionally witnessed among chimpanzees, e.g., when mothers position whole nuts for cracking for their children, and active teaching, which so far has only been observed twice (Boesch 1991).

Matsuzawa et al. (2001) consider the learning of nut-cracking in the Bossou group, Guinea, especially founded in the spontaneity of the child, coupled with the mother's high tolerance, where the stimulus for learning does not spring from the resulting availabilty of food, but from the imitation of the mother's actions. The importance of a playful, stress-free situation for a successful learning process is stressed by van Schaik et al. (1999). General or specific stress during the possible learning situation may be accountable for the fact that chimpanzee children did not make any progress in fishing for termites for years after their mother had died (van Lawick-Goodall 1971 in Beck 1980: 172) or that the very effective throwing of canisters for purposes of intimidation by one male chimpanzee in Gombe was not taken up by others in the group (van Lawick-Goodall 1971 in Beck 1980: 177).

The critical age for learning to crack nuts is between three and five years, according to Matsuzawa et al. (2001: 563); Tomasello et al. (1987: 182) have observed the first use of tools among wild chimpanzees between the ages of four and six. However, the process of learning can already start earlier, as the example of termite fishing demonstrates. According to Beck (1980: 174), young animals below the age of two years were not observed probing termite hills. They do, however, play with tool-like objects next to their termite fishing mother, observe the fishing processes of other animals and eat a termite every now and then. After the age of two, they probe termite hills with unsuitable tools that are either too short, too long, too thick, too flexible, too bent, etc., or they probe not deep enough, not long enough, or extract the probe too fast or too clumsily. Three-year-olds already fish with longer objects and more patience, but their choices of tool and technique are still inadequate. Typical four-year-olds choose and use fishing tools like adults; while their yield is good, they still spend less time at it. The behavior of five- to six-year-old chimpanzees is indistinguishable from adult behavior. While termite fishing and the use of leaf sponges are already practiced at the age of two and mastered at the age of four, first beginnings of ant fishing are not observed before the age of four, its mastery not before the age of seven (Beck 1980: 174–76).

Juveniles learn through the observation of their peers and older individuals. Adults are much more conservative and manifest a dislike of innovations; a transmission of knowledge to older individuals, as occasionally evidenced in humans, does not occur among chimpanzees in the wild (Huffman & Quiatt 1986; Matsuzawa et al. 2001). Similar observations were made by Tomasello et al. (1987) during behavioral laboratory experiments on captive chimpanzees. In their opinion, learning does not result from the exact imitation of a behavioral strategy, but through emulation, i.e., the observation of the tool-solution-relationship and the general handling of the tool that then results in own experiments with it.

While primatologists consider a behavior a cultural marker if it is habitual and handed down through generations in at least some populations of a species, but its lacking in others is not due to genetical or ecological factors (e.g., Whiten et al. 1999; Matsuzawa et al. 2001: 557), psychologists attach great importance to the mode of transmission of handed-down behavior (Boesch & Tomasello 1998). In this context, Tomasello (2002; see chapter 9) distinguishes individual modes of learning within the social context from social modes of learning. Individual modes of learning within the social context entail a learning process geared to the environment or surrounding events without the comprehension of other individuals as intentional agents. These modes of learning repeatedly create knowledge anew and individually; the knowledge of several individuals is not accumulated. By contrast, social modes of learning (imitation and teaching), which are based on the perception of others as acting intentionally, the knowledge of other individuals can be accessed and expanded upon, leading to an accumulation of knowledge. According to Tomasello (1990: 289; 2002), this cultural learning, as opposed to individual learning, only occurs in humans. Recently, however, various experiments have yielded evidence that chimpanzees imitate as well as emulate, and are able to switch between both learning strategies according to situations (Horner & Whiten 2005; Nielsen et al. 2005; Whiten 2005). Considering the duration of the learning processes to acquire various tool behaviors in young animals (see above), a combination of different learning mechanisms that are equally dependent on the individual learning history has to be assumed.

Primates as Basis for Understanding Human Cognition

Primate studies are centered on very variable modes of behavior, observed primarily in the great apes, that are geared towards specific situations and, thus, defined as intelligent. Implicitly, they are used to derive a picture of a common ancestor with humans, whose flexibility and adaptiveness equally expresses itself in tool use, limited capacity for culture, basic communication capability, pronounced ability to learn, and complex social behavior. The results of primatological research complement archaeological findings concerning the cognitive accomplishments of early humans. Field studies on the great apes in particular are crucial, despite their limitations mentioned above, since they allow insight into the possible diversity of behavior that does not leave traces in the material record. Even our knowledge about tool behavior has been expanded with help of primate data, recording potential tools made of organic material, which are not preserved archaeologically, and various possible uses that cannot be derived from the artefacts themselves. The discussion of capacity for culture in the great apes and of the modes of non-genetical transmission of innovative behavior greatly expands the mainly technologically oriented archaeological research in tool and culture development.

Thomas Wynn (1990) criticizes the fact that the primatological approach to the understanding of the development of human thinking is largely restricted to the description of behaviors and their adaptive context, discounting their evolutionary implications. Using tool use as an example, Wynn illustrates that zoological and primatological publications often only anecdotically describe unexpected observations without interpretations or theory. Systematic studies on different aspects of a behavior, like nut-cracking among west African chimpanzees (Boesch & Boesch 1983) or group differences in termite fishing between the two chimpanzee groups in the Mahale Mountains (Uehara 1982), are less frequent. In spite of the distinct increase of systematic analyses of primate behavior in the wild since 1990, the lack of their incorporation into the dicussion of the evolution of human characteristics is still very much in evidence, although exceptions (e.g., Parker & Gibson 1979; McGrew 1992; Tomasello 2002) certainly exist. Primate studies provide insight into the behavior of our closest living relatives; explicit and comprehensive theories about the cognitive context and background to behaviors and their development are typically not their focus of research.

4 Cognition: A Matter of Definition

The previous chapter introduced primates as the cognitive approximation to humans. Tool use and production, capacity for culture, communication capabilities and learning processes are manifestations of primate cognition. But what is “cognition?” The term can be loosely translated as “knowledge” or “perception;” cognitive action is a behavior routed in perception. For a long time, only philosophical epistemology dealt with human cognitive abilities, trying to define “knowledge” as opposed to “beliefs” and “truths,” and posing the question whether and how secure knowledge can be acquired. The beginnings of cognitive science, which Francisco Varela describes as the “scientific analysis of perception and knowledge in all their dimensions and workings,” are found in the first half of the twentieth century. Predominantly implemented in artificial intelligence and information processing, cognitive science expanded the focus of cognition from humans to other organisms and to anatomical, neurobiological and neuropsychological studies on the biological basis of thinking processes and the structure of the mind, as derived from behavioral studies.

Basic cognitive models compare intelligence to computing processes and equate thinking with information processing. The brain is considered the hardware, with a central processing unit and various data storage facilities, making it a knowledge creating device that has evolved in adaptation to the given environment of a species. Analogously within the metaphor, the structure of the mind as the largely innate organization of thinking processes is compared to the software. While the software's functioning is attuned to the physical level, its structure is independent from it. Functional models of cognition therefore deal primarily with the architecture of the mind, while its neurobiological basis is considered separately (Cela-Conde & Marty 1997: 328)

The origin of these so-called cognitivistic models (see Varela 1990: 37–53) is found, on the one hand, in the phylogenetical considerations on the evolution of human cognition as put forward by Konrad Lorenz and subsequent evolutionary cognition theorists. On the other hand, these ideas stem from research into artificial intelligence and cognitive psychology. Owing to their relatively simple implementation in mechanical systems – from which they are partially derived – cognitivistic models are very popular in cognitive sciences. Information units classified as “symbols,” physical representations of the facts to be processed, are processed according to rules that are comparable to a syntax and obtain their meaning through this grammatical structure. Varela (1990: 44) subsumes this prevalent direction of research under the cognitivistic paradigm, “the brain processes data from the outside world.” However, these approaches to the understanding of (human) thinking present serious problems. Since neither symbols representing single aspects of the environment nor adult structures of thinking processes are directly available at the time of birth, the question is just how a cognitive system is able to build complex memory patterns from its basic structure and contacts with the environment. For example, how does the undifferenciated cognition of a child obtain adult expert knowledge? On an even more fundamental level, the notion of symbols as representative information units has to be challenged, since neither physical units as raw materials for information processing in the brain nor syntactic rules can be detected.

For that reason, connectionistic or emergence models (see Varela 1990: 54–87; Cela-Conde & Marty 1997: 328) offer general awareness models of an analogous structure of brain, mind, and computerized information processing. Furthermore, they define cognitive capabilities as developmental processes: Humans are not born with full-blown cognitive capabilities, but have to activate and expand their genetic potential in the course of their individual development. A cognitive organism not only incorporates the present reality into its established cognitive apparatus, imaging it therein, but also organizes itself through interaction with the environment. Thus, a mass of unspecific neurons are transformed into structures of neural networks by connections that change according to their frequency of activation. In these models, cognition is not predetermined by the components of the cognitive apparatus, but rather emerges from the system properties that are superordinate to the individual unspecific elements, i.e., the connections. In connectionistic systems, it is not the symbols that function as information carriers, but the complex sub-symbolic activity patterns which form the network. The processing of symbols, for example in language, seems to be but one – highly limited and specialized – form of cognition. The emergence of neural networks and, thus, the cognitive capability mainly depends on the prevailing environment and the problems faced during the development of an individual.

However, connectionistic models also oversimplify the process of cognitive development in assuming that individual environment and problems are externally imposed benchmarks. Maybe the greatest cognitive achievement of living creatures is the detection of problems within a vast environmental framework. “These problems are not given, but *enacted, brought forth* by a background” (Varela 1990: 90). Thus, cognition not only effects the solution of any given problem, but serves to outline the problem in the first place, separating it from its obscuring context. Only if the external environment could be equated – however minimally – with the distinct world of an individual could this environment be represented or imaged in the cognitive process of this world. Yet, the world of an individual is not purely objective or independent from the experiencing subject. The brain does not process objective informations gathered by perception, but actively construes them (Cela-Conde & Marty 1997: 335). Already the perception of, for example, a pedestrian on the sidewalk has to be considered the active formulation of a hypothesis about the informational unit “pedestrian,” and not as the mere mirroring of the surrounding reality, where the pedestrian would be lost in the white noise of all simultaneous visual information. While a cognitive organism relates to its environments, it generates its own inner world by combining single parts of this environment with its own memories, experiences, and evaluations. Therefore, cognitive characteristics can never be perfectly attuned to any given environment; they remain the result of historical sequences of viable actions that generate regularities (Varela 1990: 116). Consequently, scientific cognitve models of “bringing forth a world” (Varela 1990: 88–121) consider cognition to be the capability to construe sense and meaning, and where informational units are not composed by any given order, but by individual regularities.

The different approaches to cognitive capabilities within cognitive science trace the three dimensions of the evolution of human cognition. The first dimension is phylogenetic; it corresponds to the evolution of the anatomical structure of the brain, its cerebral functions on the cellular level, and the organization of the mind. Although the acquisition of individual cognitive abilities is explained by emergence models, the structural physical and psychological foundations of the evolution of this cognitive apparatus remain a phylogenetic problem. The following chapter will present approaches to the evolution of the human brain from the fields of evolutionary epistemology, neuroanatomy, and genetics, as well as models for the organization of thinking processes. The second dimension in the evolution of human cognition is ontogenetic; it is predominantly studied in cognitive psychology. Its basic and still most popular approach is the – much criticized – stage model by Jean Piaget (see chapter 8), which already entails the beginnings of another dimension. This third and so far largely neglected dimension is historical-cultural. Human cognitive reference points are not generated over and over again on a completely individual level. Rather, the construction of the world is dependent on a cultural basis that has been influenced by the history of the society, the group, and the different subgroups to which a certain individual belongs. Approaches to the evolution of the cultural construction of the world are found in developmental psychology and in the philosophy succeeding Heidegger.

The particular mode of the evolution of human worlds also has its foundations in biology, and thus unites all three dimensions to form a single space. Humans as cognitive beings do not evolve in a single dimension, but simultaneously as biological species, as individual, and as part of a culture shaped by historical processes. All three dimensions are necessary to understand human cognition, none of them suffices alone. Only the combined study of those three evolutionary strands will enable us to comprehend the particular process of how humans learned to extend their capacity to act through cognition.

II The Evolution of Human Thinking

5 The Evolution of Human Thinking as Phylogenetic Problem: Epistemological Background

The first attempts to approach the cognitive capacity of humans as an evolutionary question from a philosophical perspective date back to the nineteenth century. Evolutionary concepts were already being discussed in several fields of study, when in 1853 Auguste Comte developed his history of human cognition in three societal stages. In his opinion, theological, fictitious knowledge, which had dominated antiquity through the Middle Ages, gave way to first cognitive steps in a metaphysically abstract and anarchical stage of transition. From early modern times on, this transitional stage exhibited attempts to incorporate scientific insights into the existing theological systems. The most progressive and modern stage was reached with the emergence of positivism and academic thought and was grounded exclusively in empirically proven facts. In true evolutionistic manner, Comte viewed his evolutionary sequence of cognitive capacity as the further development of the hierarchies prevalent in the animal kingdom, with a tendency towards evermore complex and perfected characteristics.

As early as 1891, the palaeontologist H. Potonié (1913) concluded that Darwin's theory of evolution could not only be applied figuratively to the development of the mind but also had to be adaptable to the physical bases of mental processes. Likewise, the anatomist and prehistorian Max Verworn (1915) regarded the complete history of human culture and ideas as a phylogenetical problem that could be solved through the study of its neuronal foundations and prehistoric research. He interpreted human thinking as becoming progressively distant from actual sensory input. Verworn postulated an era of the sensory-impressionistic mind, where the mental development of humans equated that of the higher animal species and object use, but not tool production, was possible. This was followed by an era of the naive-practical mind, which comprised tool production and culminated in “naive aesthetical actions” that included concepts of form, tool types, and artistic expressions relating to nature (*ibid.* 39–40). Towards the end of the Palaeolithic, he assumed the transition to an era of the theorizing mind, which is characterized by the mental confrontation with the self and its environment: life, death, body, mind, past, future, invisible powers, and the origins of animals, plants, heaven, earth, the sun and the stars. This era was subdivided into a first, dogmatic-speculative, phase, which itself was divided into a stage of mythical-religious conjecture that extended until the Iron Age and a stage of scholastic-rational conjecture that started with the ancient philosophers. It is only with

Renaissance that the second phase of the theorizing mind begins – a phase of critical-experimental thinking, where conjectures and theories have to be validated rationally through experiences and scientific experiments (*ibid.* 41-44).

During the first half of the twentieth century the question of the evolution of human cognition was expanded to include the biological phylogenetic history of mankind on the basis of ethological and biological studies. In the spirit of Auguste Comte, the question was referred to philosophy under the assumption that empirical and scientific answers could be found. The ethologist Konrad Lorenz (1941) was the first to take up the challenge of answering philosophical questions by biological means, in his paper on "Kant's Doctrine of the A Priori in the Light of Contemporary Biology." There and even more explicitly in his later work "Behind the Mirror: A Search for a Natural History of Human Knowledge" (1973), Lorenz combined cognitivistic models of cognition (see chapter 4) with evolutionary ideas, ontogenetic elements and cultural aspects, and from that combination developed a theory of the biological and phylogenetical basis of human cognition.

Konrad Lorenz: Essay of a Natural History of Human Cognition

Like all organic systems, humans gather information and adjust to their environment; life and evolution are therefore, after Lorenz (1973), cognitive processes by themselves. Information about the external environment is imprinted into a living system: each adaptation constitutes a gain of knowledge. With each intake of information the cognitive apparatus changes in order to increase the chances of further gains of energy or knowledge in the genome, as well as in individual cognition, and to align the direction of development with the environment. The gain of new information expands the action radius of a system. On the one hand, the gathering of information can happen on a short-term basis and without storage in simple closed systems, which do not allow for further adaptation but only for the functioning of already adapted structures. Instinctive actions – species-specific fixed action patterns that are executed without the involvement of receptors after being initiated by key stimuli – as well as appetitive behavior, the search for stimuli that trigger instinctive actions, are based exclusively on phylogenetically acquired information and thus form an individually unchangeable framework of behavior. Open systems, on the other hand, allow for the execution of the most appropriate of several behavioral options because of individual, externally induced modifications. They are the foundation of practice, habituation and imprinting, an irreversible fixation to a stimulus situation. Besides an open program, learning through success or failure requires a memory of the program's process and a relationship between the process and success by means of receptor feedback, but the process itself does not necessarily have to be a rational one. For example, the trigger for building nests in jackdaws is innate, as is the typical action for securing structural elements of the nest, the so-called tremble shoving. When using specific suitable materials, the tremble shoving ends orgastically; thus, the jackdaws learn which materials return enforced feedback (*ibid.*: 128).

Curiosity behavior constitutes, after Lorenz (*ibid.*: 195–203), a further expansion of adaptive capabilities. Since curiosity behavior can activate all inherited behavioral patterns and permits their testing against an object, for example in play, the characteristics of different objects in the environment can be learned. Thus, for curious creatures the environment is not formed by innate trigger mechanisms but can be actively explored, since the phylogenetically inherent programs are exceptionally open. In these situations, appetitive behavior is generalized: it is the learning situation itself that provides motivation, instead of the search for a specific situation that will trigger the stimulus. Lorenz considers self-exploration a special form of curiosity behavior. The simultaneous perception of an action through hands and eyes and the exploration of a similar body during play transform the own body into an object that is comparable with other objects. Thus, a new option of objectification and reference to the environment is created: grasp turns into comprehension. While Lorenz considers the effects of self-exploration and the development of a subject in contrast to surrounding objects exclusively among humans, present knowledge suggests that these results are also applicable to the great apes, and maybe to other species as well (see the experiments by Gallup 1975).

Besides language, the accumulation of supra-individual knowledge, the assessment of the probable outcome of individual actions, and responsible morals, Konrad Lorenz considers abstract thinking to be the epitome of hominization. The roots of abstract thinking are found in various cognitive partial functions (Lorenz 1973: 157–215) that are not all exclusively human. One of those fundamental aspects is the abstracting perception of an object in different situations, or conception of categories, which enables initial and repeated recognition of patterns. These patterns allow the transfer of experiences to other situations. Additionally, rational actions and imagined simulations of actions define human thinking. Furthermore, humans are capable of random movements that can be activated at will, where new, as yet unlearned motion sequences can be assembled from small motor units. Feedback from random movements and curiosity behavior are the foundations of knowledge gain through active exploration of the environment in humans, and the transmission of knowledge among individuals of our species is very pronounced. While the great apes, for example, acquire an understanding of a situation by observing others and subsequently try to solve the problem themselves (emulation), only humans and some birds are capable of reconstructing motion sequences as exactly as possible for the sake of reconstruction alone, i.e. to imitate them.

Random movements, as well as the monitoring of external and self-perception, are preconditions of imitation. Although knowledge traditions have been observed in animals, Lorenz considers them to remain exclusively object-oriented as opposed to human traditions. The lack of an object of tradition, such as cats as feared predators among jackdaw populations, during only one generation can already easily break the chain of tradition. Only abstract thinking in combination with spoken language renders traditions object-independent, according to Lorenz.

Cumulative, object-independent traditions lead to the transmission of acquired characteristics, both vertically, bridging generation gaps in both directions, and horizontally, extending to non-related members of the same species: the supra-individual storage of knowledge is not anymore restricted to the genome, but increasingly occurs as culture in the mind of humans (*ibid.*: 228–30). According to Lorenz, cultural evolution progresses through transitions, similar to the evolution of species, but different in that inventions and parallel developments occur frequently, whole complexes of characteristics are transferable to other cultures, and cultures can easily merge again. The foundations of a culture's development capability lie in the equilibrium between invariance and adaptability. The accumulation and inheritance of knowledge require adherence, further development requires gradual reduction of knowledge (*ibid.* 255–61). Habituation, imitation, and the development of rites and symbols lead to the restriction of variability and thus to control. Through their own creation of a surrounding world of objects, humans limit their experience of a human-independent, extra-subjective reality (*ibid.* 285). This restricting tradition is balanced by curiosity, which is a typical human trait and persists into adulthood.

To explain the particularity of the human mind, Lorenz introduces the term “fulguration” to denote emergence in evolution (*ibid.* 48–55). He defines fulguration as the fusion of previously independent subsystems into a new integral system that displays some completely new properties which cannot be ascribed to the functioning of the subsystems. With this device of evolutionary theory, Lorenz posits the evolution of humans from animal ancestors, including the appearance of new, exclusively human properties, especially in cognition (*ibid.* 64, 223). As an example, he refers to the linguistic symbolism of true “word languages,” which, in his opinion, evolved from the fulguration of the vague symbols of cultural ritualization and conceptual thinking (*ibid.* 302).

Evolutionary Epistemology – The End of Philosophical Epistemology?

Evolutionary epistemology, which equates thinking and cognition with biological functions of the brain, constitutes the strictly biological continuation of Konrad Lorenz's biological-philosophical approaches to the evolution of human cognitive abilities (see Irrgang 2001). According to this concept, the description of the physical structures of cognitive faculties can explain the evolution of cognition. This cognitivistic approach is best explained by contrasting some general assumptions of philosophical epistemology and evolutionary epistemology (Table 1).

Their main difference lies in their respective definitions of knowledge (*ibid.* 36). While evolutionary epistemology generally equates knowledge with the objective gain of information, or "intelligence," and looks for the evolution of cognitive capabilities, philosophical epistemology perceives knowledge as the rationalized understanding of an object through a subject; it investigates the process of how an individual attains factual knowledge through perception and how this knowledge is validated. In contrast, evolutionary epistemology reconstructs the development of information acquisition and processing without referring to a perceiving subject, thus taking an exclusively observational approach.

Evolutionary Epistemology		**Classical Epistemology**
Knowledge = Gain of Information	**COGNITION**	Knowledge = Substainable Comprehension
Evolution		Application
Competence		Execution
Subject-free cognition		No cognition without subject
Observer perspective		Participant perspective
Objective: Reconstruction		Objective: Argumentative Justification
Scientific-empirical approach		Metaphysical approach

Table 1 Comparison of approaches to "knowledge" and cognition.

Since evolutionary epistemology is not based on a unified model of biological evolution, multiple evolutionary approaches are applied (*ibid.* 50–79). Different processes, such as mutation, selection, random genetic drift, and the self-organization (*autopoiesis*) of organisms have been recognized as evolutionary factors, the attributed importance of which is contingent upon the theoretical approach under consideration. Generally, adaptation – the adjustment of an organism to its environment or ecological niche – is considered to set the pattern for evolution, but its exact nature is still under debate. If it were an optimization of adjustment caused by selection, better adapted organisms would benefit in terms of survival and reproduction. According to the concept of *autopoiesis,* the important factor is the preservation of the adaptation: if adaptation is homeostasis, i.e., an adjustment of equilibrium, adapted organisms survive – there are no *better* adapted organisms. When adaptation is viewed as the open co-evolution of organism and environment, the inherent dynamics of evolution prevent complete adaptation. Selection can take different forms: internal, external, stabilizing, directional, disruptive, hard, and soft; its scope, whether on a genetic, cellular, or individual level, or within populations or species, remains unclear.

The example of evolutionary epistemology, which set out to solve philosophical questions of cognition by purely biological-evolutionary means and has failed doing so (cf. Löw 1983; Irrgang 2001), illustrates the limitations of cognitivistic models. Although evolutionary epistemology expands our knowledge of the evolution of human cognition during phylogeny and the cognitive capabilities of non-human beings, it has to be complemented by other approaches, such as Jean Piaget's connectionistic studies. These place more emphasis on the construction of world views as cognitive actions, as opposed to viewing cognition as a portrayal of reality enhanced by evolutionary processes. Following Irrgang (2001: 38), evolutionary epistemology should be further developed into an evolutionary cultural anthropology dealing with the specifically human form of intelligence as interaction with nature and culture, thus closing the gap between the ontogenetic evolution of cognitive capabilities and the individual development of cognitve capabilities during ontogenesis. A prerequisite for this development is the reconstruction of the evolution of the cognitive apparatus, which in its last stage – hominization – has until now remained largely speculative, as well as a more detailed differentiation between pongid and human cognitive apparatus than evolutionary epistemology has employed so far.

6 The Evolution of Human Thinking as Phylogenetic Problem: Anatomical, Neuropsychological and Genetic Basics

The course of human evolution (fig. 2) led to numerous physical changes. The earliest evidence indicating upright walking in the hominid family comes from the 6-million-year-old fossil finds of *Orrorin tugenensis* (Senut et al. 2001) and *Sahelanthropus tchadensis* (Brunet et al. 2002; Zollikofer et al. 2005). Around 4 million years ago, early australopithecines already displayed distinct skeletal adaptations to bipedal locomotion. However, up to and including *Homo habilis*, hominid individuals were small in stature, with long muscular arms, robust and curved phalanges, a pelvis with big iliac wings and small acetabula, short femora, and long, curved tarsal phalanges (McHenry and Coffing 2000). This group of early hominids, which walked upright but still displayed numerous adaptations for climbing trees, also displays a marked sexual dimorphism in body height.

From 1.8–1.6 million years before present on, *Homo ergaster,* the early African form of *Homo erectus*, shows a reduced sexual dimorphism, while at the same time clearly increasing in physical height. The bodily proportions correspond to those of modern humans, with long and robust legs and shorter arms. The chest is barrel-shaped, the pelvis, with its smaller iliac wings and larger acetabular diameter, resembles modern ones, and the phalanges of hands and feet have straightened. From these data, Henry McHenry and Katherine Coffing (2000) posit that a number of far-reaching physical changes took place between 2.5 and 1.8 million years before present. The fossil remains of *Homo rudolfensis* may turn out to be the connecting link between australopithecine (including *Homo habilis*) and human physique; however, so far only few postcranial skeletal remains of this species have been found.

Increase in Brain Size

Apart from changes in the musculo-skeletal system, it is mainly the increase in brain size that characterizes human physical evolution. It is evidenced by the measured or estimated internal cranial capacity of a few relatively well preserved individuals (fig. 3 and Table 2).

The earliest hominids for which measurements could be taken from reconstructed skulls date to 3.2–2.5 million years before present (MA). According to McHenry and Coffing (2000), as well as Tobias (1995), the cranial capacity of these australopithecines averages at 450 cm^3 or below, which is barely higher than the average modern chimpanzee brain size. There is no discernible trend in evolution between *Australopithecus afarensis, Australopithecus africanus,* the late, gracile *Australopithecus garhi,* and the early, robust *Australopithecus aethiopicus.* However, beginning with 2 million years before present, the absolute brain capacity begins to increase. According to McHenry and Coffing, the robust forms *Australopithecus boisei* and *Australopithecus robustus* also resemble each other in relation to their slightly increased brain volume, while Tobias (1995) only notes a minimal increase in *Australopithecus boisei*. Additionally, Falk et al. (2000) base their similar assessment of no significant acceleration in brain development in this group on new brain volume estimates of several individuals from all three robust australopithecine (resp. paranthropine) species. Although the brain volume of all *Homo habilis* individuals that could be estimated is higher than that of the australopithecines, its 601 cm^3 are still considerably lower than the 763 cm^3 of the approximately contemporary *Homo rudolfensis* individual KNM-ER 1470 (ibid.).

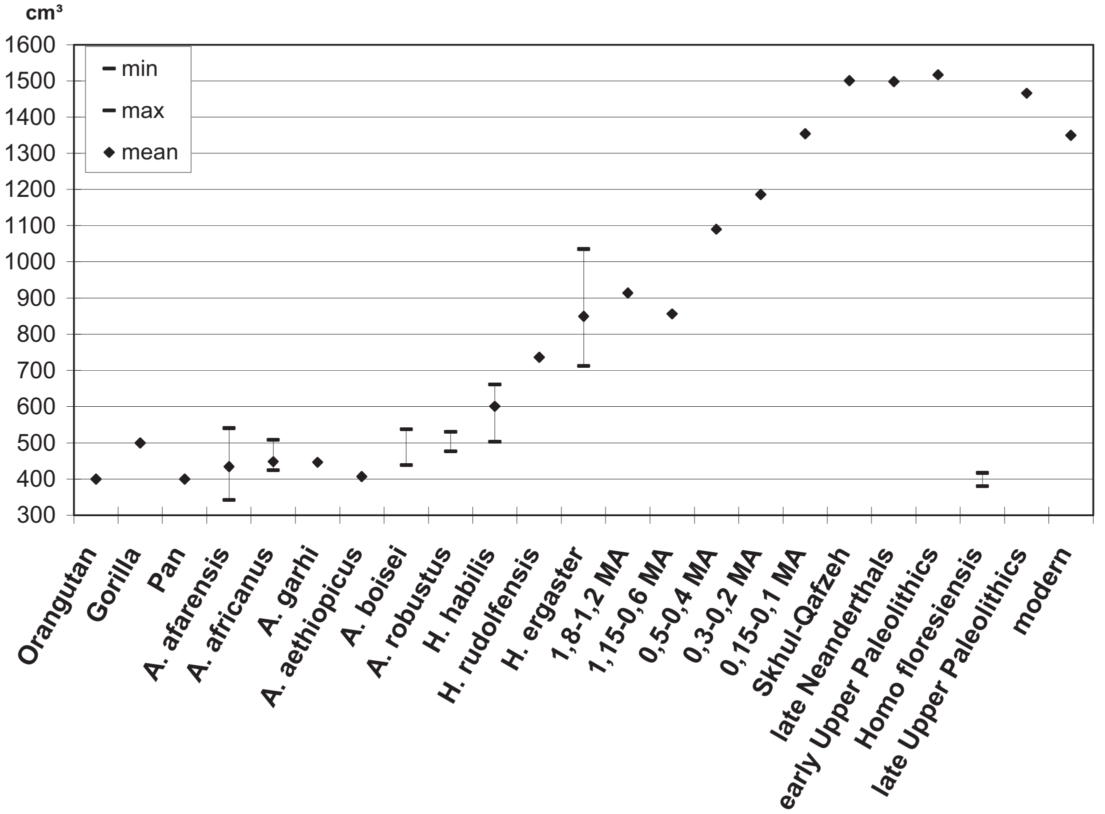


Fig. 3 Increase of mean cranial capacity in cm^3 (after Ruff et al. 1997; McHenry and Coffing 2000; Falk et al. 2005).

Species	**Individual**	**Cranial capacity (cm^3)**	**Ref.**
Pan troglodytes	∅	ca. 400	1
Australopithecus afarensis	∅, n = ?	438	1
	∅, n = 3	413,5	2
A. africanus	∅, n = ?	452	1
	∅, n = 6	440,3	2
	∅, n = 7	451	4
A. garhi	BOU-VP-12/130	450	1
A. aethiopicus	KNM-WT 17000	407	1
A. boisei	∅, n = ?	521	1
	∅, n = 7	463,3	2
	∅, n = 6	452	4
A. robustus	SK 1585	530	1
		476	4
Homo habilis	∅, n = ?	612	1
H. rudolfensis	KNM-ER 1470	752 bzw. 736	1, 6
H. ergaster	∅, n = ?	871	1
Lower Pleistocene *Homo* 1,8-1,2 MA	∅, n = 5	914 ± 45	3
Lower to early Middle Pleistocene *Homo* 1,15-0,6 MA	∅, n = 7	856 ± 52	3
Middle Middle Pleistocene *Homo* 0,55-0,4 MA	∅, n = 12	1090 ± 38	3
Final Middle Pleistocene *Homo* 0,3-0,2 MA	∅, n = 17	1186 ± 32	3
Upper Pleistocene *Homo* 0,15-0,1 MA	∅, n = 8	1354 ± 41	3
Qafzeh / Skhul	∅, n = 6	1501 ± 45	3
Late Neanderthals 75-36 kA	∅, n = 14	1498 ± 45	3
Early Upper Paleolithics	∅, n = 15	1517 ± 30	3
H. floresiensis	LB 1	380 bzw.417	5, 6
Late Upper Paleolithics 21-10 kA	∅, n =	1466 ± 35	3
H. sapiens	∅	1349	3

Table 2. Brain volume of different hominids. Cited after (1) McHenry and Coffing 2000, (2) Tobias 1995, (3) Ruff et al. 1997, (4) Falk et al. 2000, (5) Brown et al. 2004, (6) Falk et al. 2005.

While both McHenry and Coffing (2000) and Ruff et al. (1997) note a distinct increase in brain volume for *Homo ergaster* and other *Homo* specimens during the Early Pleistocene, between 1.8 and 1.2 million years before present, the values derived from individuals between 1.15 and 0.6 million years appear to be stagnant. It is only during the middle of the Middle Pleistocene (550,000–400,000 years before present) that the measurable fossils exhibit an increase in estimated brain volume. In the early anatomically modern humans from Skhul and Qafzeh, the brain volume peaks at 1500 cm^3, a volume they share with the late Neandertals and early Late Palaeolithic individuals. After the last cold maximum, the late Late Palaeolithic populations show a slight but steady decrease in volume – a continuous trend that results in the average modern brain volume of 1349 cm^3. Ruff et al. (1997: 175) consider it to parallel the decrease in mean body weight. This general evolutionary trend is offset by the 2004 discovery and description of the species *Homo floresiensis*. This miniature human species lived on the Indonesian island of Flores until maximal 13,000 years ago and possessed an estimated brain volume of 380 cm^3 (Brown et al. 2004) or 417 cm^3 (Falk et al. 2005).

Direct comparison of the average brain volumes of different species bears numerous risks. The small number of fossils sufficiently preserved to allow the measurement of their endocranial volume severely limits the comparative assessment of increases in brain size during the course of human evolution; in case of incomplete preservation, measurements or estimates can differ considerably (cf. D'Amore et al. 2001: Table 1). On the small basis of chance discoveries, the actual range of variation and the average values of one species cannot be determined. In case of changing species assignations of individual fossils (e.g. from *Homo habilis* to *Homo rudolfensis*) the classification with one group or the other will distinctly change the respective range of variation and average values. Coincidentally, varying proportions of the male to female ratio in classifiable fossils will additionally raise or lower the average brain volume, especially in species with a marked sexual dimorphism. Finally, the mean absolute cranial capacity of a species is highly dependent on its average body weight. This last problem can theoretically be counterbalanced by the calculation of the encephalization quotient.

Encephalization Quotient

There exist different established ratios of cranial volume or brain weight to body weight for different taxa of contemporary species. Generally, the ratio of brain weight (E in mg) – as a variable dependent on cranial volume – to body weight (P in g) can be expressed by the allometric regression formula $E = k \times P^a$ or $\log E = \log k + a \times \log P$, where the exponent a and the coefficient k vary for different taxa. From the respective approximate equations for certain taxonomic categories, expected values of average brain weight or cranial capacity for a species can be derived with the help of this species' mean body weight. Thus, in order to be able to compare cranial capacities independently from body weight, the expected cranial value (endocranial volume, brain volume or brain weight, E_{exp}) according to body weight needs to be put in relation to the actually observed value (E_{obs}). This is exactly what is expressed by the encephalization quotient (EQ): $EQ = E_{obs} \times E_{exp}$.

From the regression formula established for placental mammals, $E_{exp} = 58.99 \times P^{0.76}$ (Martin 1981: 57, formula 6, E in mg, P in g), McHenry and Coffing (2000: 127) developed the formula for the encephalization quotient $EQ = E_{obs} \times (11.22 \times P^{0.76})$, with E in g and P in kg. The calculation of the EQ for different fossil hominid species is based on the estimated average body weight (P_{exp}) and the brain weight (E_{obs}) established through measured or estimated cranial volumes.

In contrast to the absolute values of brain volume, McHenry and Coffing (2000) observe a relative increase in brain weight already at the beginning of human evolution; according to their calculations, *Australopithecus afarensis* already exhibits a distinctly increased value of 2.5 compared to modern chimpanzees ($EQ = 2.0$), which were used as an approximate equivalent of a common ancestor. The authors also note a continuous increase from *Australopithecus africanus* and *Australopithecus boisei* through *Australopithecus robustus*. Within the early *Homo* species with *Homo rudolfensis* ($EQ = 3.1$) and *Homo ergaster* ($EQ = 3.3$), *Homo habilis* stands out with a comparatively high value of 3.6. McHenry and Coffing (*ibid.* 137) attribute this fact to the marked gracility of *Homo habilis,* compared to the two other, heavier forms, although the use of the encephalization quotient should have eliminated this bias. Just as with the absolute values, there are hardly any changes in the EQ to be perceived for the period 1.8 to ca. 0.6 millions years before present. It is only during the Middle Pleistocene that a further increase can be detected, again parallel to the increase in absolute cranial capacity, leading to an EQ of 4.8 among the late Neandertals. Finally, the EQ value culminates in the early anatomically modern humans of Skhul and Qafzeh as well as early Late Palaeolithic *Homo sapiens sapiens* specimens, with an almost present-day value of 5.3.

However, the seemingly more precise values of the encephalization quotient – as dependent on body weight – also contain possible sources for errors. Apart from the basic problems associated with the development of regression equations, which are listed in Deacon (1990: 201–9), the application of different equations leads to varying EQ results (see Table 3).

Species	**Sex**	**Body weight P (kg)**[1]	**∅ Brain weight E (g)**[2]	**Brain weight E (g)**[3]	**EQ after McHenry & Coffing**[4]	**EQ after McHenry & Coffing**[5]	**(EQ) after Martin (13)**[6]	**IP after Bauchot & Stephan**[7]	**CC after Hemmer**[8]
Pan troglodytes	∅	45	395		2,0		1,6	10,8	33,6
A. afarensis	∅	37	434		2,5		2,1	13,4	38,6
min	f	29		342		2,4	2,0	12,3	32,8
max	m	45		540		2,7	2,2	14,8	45,9
A. africanus	∅	36	448		2,7		2,2	14,1	40,1
min	f	30		424		2,8	2,4	15,0	39,6
max	m	41		508		2,7	2,3	14,7	44,1
A. boisei	∅	42	514		2,7		2,3	14,7	44,4
min	F	34		494		3,0	2,5	16,1	44,8
max	m	49		537		2,5	2,1	13,9	44,8
A. robustus	∅	36	523		3,0		2,6	16,4	46,8
min	F	32		523		3,3	2,8	17,7	48,1
max	m	40		523		2,8	2,4	15,4	45,7
H. habilis	∅	35	601		3,6		3,0	19,2	54,2
min	F	32		503		3,2	2,7	17,0	46,3
max	m	37		661		3,8	3,2	20,4	58,8
H. rudolfensis	∅	56	736		3,1		2,6	17,5	59,5
min	F	51		736		3,3	2,8	18,6	60,8
max	m	60		736		2,9	2,5	16,8	58,6
H. ergaster	∅	61	849		3,3		2,8	19,1	67,3
min	F	51		712		3,0	2,5	18,0	57,6
max	m	66		1035		3,8	3,3	22,2	80,6
1,8-1,2 Myr BP	∅	62	890		3,5		2,9	19,9	70,3
1,15-0,6 Myr BP	∅	58	835		3,4		2,9	19,4	67,0
0,55-0,4 Myr BP	∅	68	1057		3,8		3,3	22,3	81,8
0,3-0,2 Myr BP	∅	66	1148		4,3		3,6	24,7	89,4
0,15-0,1 Myr BP	∅	68	1307		4,7		4,0	27,6	101,1
Skuhl - Qafzeh	∅	67	1444		5,3		4,5	30,8	112,1
class. Neanderta.	∅	76	1442		4,8		4,1	28,3	108,7
early Upper Pal.	∅	67	1460		5,3		4,6	31,2	113,3
H. floresiensis									
min	F ?	36	375			2,2	1,8	11,8	33,6
max	f ?	16	410			4,4	3,6	21,5	44,2
late Upper Pal.	∅	63	1412		5,4		4,6	31,2	111,2
H. sapiens (Mc&C 2000)	∅	54	1350		5,8		4,9	32,9	110,1
H. sapiens (Ruff et al. 1998)	∅	58	1302		5,3		4,5	30,2	104,5

Table 3 Brain weight indices for different hominid species.

(1–4) after McHenry and Coffing 2000: 127 and 137, and Ruff et al. 1998. *Homo floresiensis* after Brown et al. 2004 and Falk et al. 2005.

(5) computed after McHenry and Coffing 2000: 127; $EQ = E \times (11.22 \times P^{0.76})$, E in g, P in kg. Based on Martin 1981: formula 6 (allometric regression equation brain/body weight for general mammals): $EQ = E \times (58.99 \times P^{0.76})$, E in mg, P in g.

(6) EQ computed according to McHenry and Coffing 2000: 127 from Martin 1981: formula 13 (allometric regression equation brain/body weight for mammals with long gestation period and high birth weight): $EQ = E \times (107.15 \times P^{0.72})$, E in mg, P in g.

(7) IP computed after Bauchot and Stephan 1966; 1969; cited in Stephan 1972: 158 (based on regression equation brain/body weight for insectivores): IP = $EQ = E \times (42.855 \times P^{0.63})$, E in mg, P in g.

(8) CC (cephalization constant) computed after Hemmer 1971, cited in Leutenegger 1973 (based on regression equation brain/body weight for primates): CC = $E \times P^{0.23}$, E and P in g.

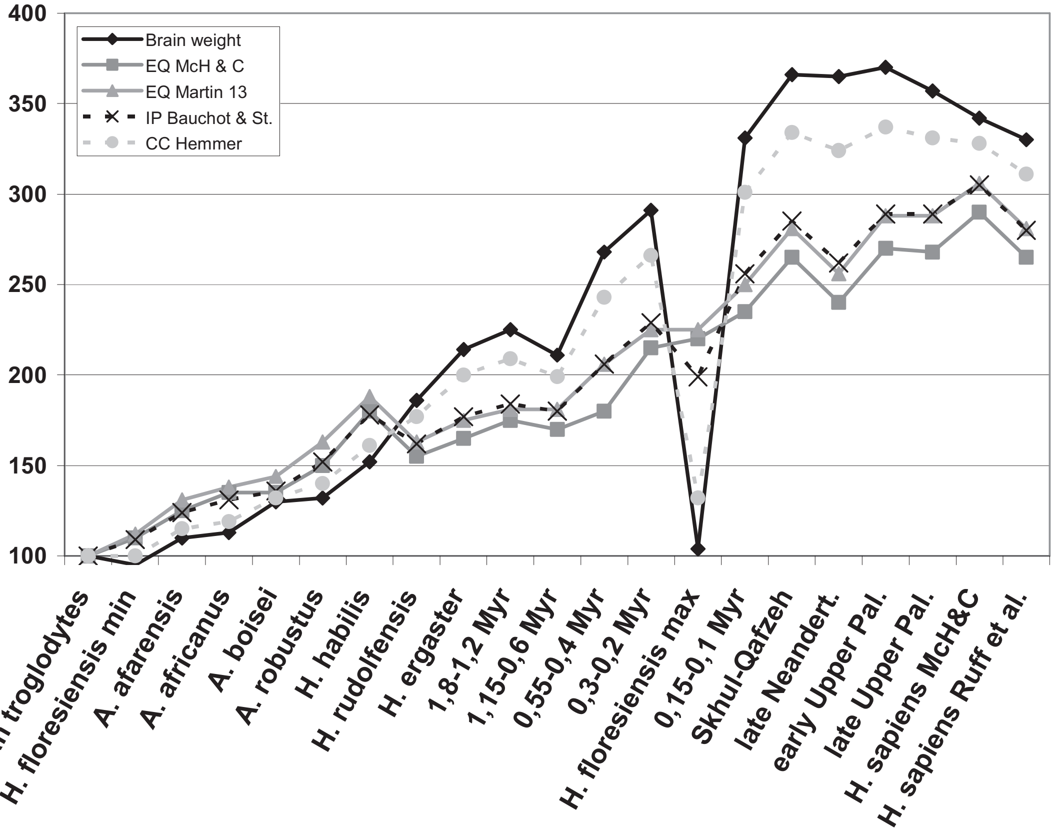


Fig. 4 Comparison of different encephalization quotients for hominid groups (in relation to *Pan troglodytes* = 100), based on values and formulas from Table 3. The placement of species along the x-axis generally follows the established chronology by first appearance. The calculations for *Homo floresiensis* were placed next to their closest corresponding values in order to illustrate the enormous differences of the results and their ensuing interpretation. Thus, the minimal values (with an estimated maximal body weight of 36 kg) are still lower than those of *Australopithcus afarensis*, while the maximal values (with a minimal body weight of 16 kg) range with those computed for typical Late Pleistocene specimens.

Figure 4 illustrates the observed brain weight and computed *EQ* values after equations by different authors in relation to the value of *Pan troglodytes* = 100. While McHenry and Coffing (2000) employ an equation generally valid for placental mammals (Martin 1981: 58, formula [6]), the use of an equation for mammals with long gestation period and high birth weight (Martin 1981: 58, formula [13]) yields slightly elevated values. If an equation developed for insectivores is used, as suggested by Bauchot and Stephan (1966; 1969; cited in Leutenegger 1973), the relative progression of the encephalization quotient resembles the one charted for formula (13) in Martin (1981). A marked difference is visible in the results derived from a formula by Hemmer (1971, cited in Leutenegger 1973), which was specifically developed for use with primates that are closely related to human ancestors. Overall, the curve shape closely resembles the one derived from absolute brain weight values. The values after Hemmer for all gracile species up to *Homo habilis* are somewhat higher than the absolute brain weight, while those for the more robust and heavier *Homo* species are somewhat lower.

When comparing closely related species, the use of a very generalized equation leads to an overestimation of encephalization for species with a low body weight and an underestimation for species with a high body weight (Leutenegger 1973: 10; Martin 1981: 59–60). While in the more generalized mammal formulas (McHenry and Coffing 2000; Martin 1981: formula [13]) the gracile *Homo habilis* clearly rises above the heavier forms of *Homo rudolfensis* and *Homo ergaster* in encephalization quotient, the application of the insectivore formula after Bauchot and Stephan (1966; 1969) results in almost identical values for *Homo habilis* and *Homo ergaster*. If the formula for pongids after Hemmer is used, the degree of encephalization for *Homo habilis* is lower than that of *Homo rudolfensis*, which in turn is eclipsed by the value for *Homo ergaster*. Thus, the remarkably high *EQ* value for *Homo habilis*, as compared to *Homo ergaster*, after McHenry and Coffing (2000: 137) may be the product of the application of an equation less suited for hominids.

The exceptional position of *Homo floresiensis* as the evolutionary result of an isolated insular population is mirrored in its values for absolute brain volume as well as the different computed *EQ*s (see Table 3 and fig. 4). If a high body weight of up to 36 kg and the lower brain volume estimate of 380 cm^3 (Brown et al. 2004) are assumed, all possible equations for the *EQ* lead to the same result: the value is always close to the chimpanzee values and never reaches those of *Australopithecus afarensis*. A lower body weight of 16 kg (*ibid.*) and the higher brain volume estimate of 417 cm^3 (Falk et al. 2005), however, yield astonishing results. While the *EQ* of *Homo floresiensis* after the pongid formula (Hemmer 1971) only resembles that of *Australopithecus boisei*, the application of the more generalized formulae raises the *EQ* to a level corresponding to late Middle Pleistocene *Homo* individuals. On the one hand, this may be the result of overestimated encephalization in a low-weight species owing to the use of more generalized equations; on the other hand, though, it may be that the formula for placental mammals is more suitable in case of isolated evolution with possibly “special allometric constraints” (Falk et al. 2005: 245) than an equation developed exclusively for pongids and their relatively uniform evolutionary progression. The morphology of a virtually generated endocranial cast of the *Homo floresiensis* specimen LB1 certainly puts this individual in close proximity to classical *Homo erectus* finds, with several clearly advanced features (Falk et al. 2005).

The comparison of encephalization quotients only permits to chart the evolution of the brain on a more generalized level; the evolutionary stage of the brain of a single species cannot be deduced directly from the *EQ* values. The mean body weight does not constitute a fixed standard, its development is just as variable as that of the brain weight. Thus, a higher *EQ* can be explained by a concomitant high increase in brain weight and a slow increase in body weight (Deacon 1990), while a lower *EQ* may be the result of a minor increase in brain weight concomitant with a higher gain in body weight, as Byrne (1996) has discussed for gorillas. According to Maciej Henneberg (in Aiello and Wheeler 1995: 213), the encephalization of the species *Homo* is possibly not the result of a disproportionate increase in brain size, but rather owed to the fact that the body weight did not increase proportionally as expected: "It seems that this general 'structural reduction' of the human body is responsible for our large encephalization quotient." This relative decrease in body weight, coupled with the resulting decrease in efficiency, may have been brought about by the externalization of physical functions, as witnessed for example in tool use.

Additionally, when computing the encephalization quotient of fossil species, the expected brain volume cannot be established through observed body weight, but has to be extrapolated from other features, such as the surface areas of the first mandibular molar, a vertebra section, or the femoral diameter; from these measurements the expected body weight is estimated with the help of yet another allometric regression equation. In individual cases, the expected body weight can differ considerably from the actual body weight, which in the case of male gorillas, for example, lies an average 25.6 % above the estimated weight, while at the same time being an average 26.9 % lower in female gorillas (Smith 1996: 453). Apart from this margin of error in the relation between brain size and the features that the estimated body weight is based upon, this method of estimating the brain size is also subject to the problem of accumulating confidence intervals (*ibid.* 456).

The unknown extent of sexual dimorphism in fossil species affects the evaluation of the *EQ*s in various ways. The difference between male and female individuals according to their estimated body weight can vary considerably from the dimorphism detected in actual body weight, so that, for example, an overestimation of female body weight can lead to the underestimation of female *EQ*s (Smith 1996: 455). In extreme cases, like the markedly dimorphic orangutans, female individuals exhibit an *EQ* 1.5 times higher on average, based on observed body weight, than the males (*ibid.* 453). Additionally, the sexual dimorphism expressed in the features used to estimate body weight, like the surface area of the first mandibular molar, can differ from other features, such as body or brain weight, thus further complicating the relation between these features and the brain weight (*ibid.* 460). Finally, the variables applied in the comparison of *EQ*s during the course of hominid evolution are not differentiated by sex; rather, average body weight, derived mean brain weight, and a small sample of measured cranial capacities, not differentiated by sex, are employed. Since the expected brain weight and, thus, the *EQ* vary according to the body weight used in the calculation, the percentage of male to female individuals is crucial, especially in species with a marked sexual dimorphism (cf. Table 3). D'Amore et al. (2001) tried to circumvent this problem of uncertain sex determination by employing statistical means when dealing with samples, assuming a Gaussian distribution of the basic population. However, Ipña and Durand (2001) have conclusively demonstrated that sexually dimorphic features constitute basic populations that result from two Gaussian distributions and, as such, cannot be treated as a normally distributed basic population.

Despite the undeniable theoretical advantage of assessing the evolution of brain size in hominids with help of the encephalization quotient, which mathematically eliminates the influence of body weight, several basic methodological problems can not be ignored; these are especially prevalent when *EQ* comparison is used with fossil material. The problems with the raw data, discussed above in relation to absolute brain size, also come into play when computing *EQ*s. Considering the similarity of the values for observed brain weight and the computed encephalization quotients after the pongid formula by Hemmer in figure 4, it becomes clear that brain weight constitutes an approximation of the evolution of hominid brains which is not really improved by the use of methodologically problematic *EQ* calculations. Only in exceptional cases, like that of *Homo floresiensis*, which do not follow the general trend of hominid evolution, can an approach with help of an allometric equation, such as that developed for placental mammals, possibly yield more informative results.

Despite these problems, the study of species differences in brain volume and encephalization quotient cannot be completely disregarded – especially if the methodological problems are taken into consideration. Like other physical features or their derivations, they can indicate morphological variability and serve as a statistical basis for species comparison, sexual dimorphism, and intra-species variation (Holloway 1972: 191), as showcased in Rightmire's study (2004) on the differentiation between *Homo erectus* and *Homo heidelbergensis*. The cognitive basis for the interpretation of the encephalization quotient as an indicator of a greater or lesser potential for intelligence is still largely missing – although tentative evidence for a very cursory correlation exists (Deacon 1990: 195–201). For the time being, however, a close correlation between brain size and intelligence still has to be rejected as misleading, as Holloway notes (1972: 191).

Energy for Brain Growth

Despite all criticism regarding the base data and their ensuing interpretation, it is an undisputed fact that during the course of hominid evolution the size and volume of the brain increased in absolute values as well as relative to body size. Since, in resting state, the relative basal rate of the brain's metabolism in relation to its weight is nine times higher than the average rate of all other tissues, Leslie Aiello and Peter Wheeler (1995) discuss the various ways in which energy for the growth of energy-consuming brain tissue can be gained. Studies on living primates showed no correlation between a higher basal metabolic rate and increased encephalization. Since there is also no decrease in the basal metabolic rate of other body tissues to be detected, Aiello and Wheeler consider the reduction of the relative mass of other organs as the probable source of the energy needed.

Energy-wise, the heart, kidneys, liver, and gastro-intestinal system are equally demanding as the brain. A comparison of the weight of different organs between an average human of 65 kg and an average primate of the same size shows similar values for heart, kidneys, and liver, but a 40 % smaller gastro-intestinal tract in humans. Thus, the co-evolution of a smaller gastro-intestinal system could compensate the energy needed for increased brain growth. However, smaller intestines and simpler stomachs, like those of carnivores, depend on small amounts of easily digestible and high-energy food. Aiello and Wheeler conclude that high-quality food constituted an indispensable precondition for the disproportionate brain growth during human evolution, regardless of the selective advantages of a relatively bigger brain. The authors interpret the barrel-shaped torso and narrower pelvis of *Homo ergaster* – as opposed to the funnel-shaped torso and wide pelvis of the australopithecines – as first indicators of a smaller gastro-intestinal system; this would chronologically coincide with the first general increase in *EQ*, approximately 2 million years before present. They associate the second significant increase in *EQ*, which took place towards the end of the Middle Pleistocene, with the use of fire by archaic *Homo sapiens*, which may have lead to improved digestion due to heated food. Wrangham et al. (1999) consider boiled tubers with a high starch content to be the probable high-energy food source that promoted brain growth as early as in early *Homo ergaster*, 1.8 million years before present.

Maciej Henneberg (in Aiello and Wheeler 1995: 212–13) puts the augmented energy demand caused by a bigger brain into perspective. After his calculations, the increase in size from an average primate brain to the modern human brain – assuming equal body size – only accounts for 10.5 % of the basal metabolic rate in resting state and for 5.8 % during moderate physical activity, such as, for example, a 45-minute walk. Slightly longer resting phases would, in his opinion, suffice to compensate for the higher energy demand. Wrangham, Jones, and Leighton note (*ibid.* 216) that the basal metabolic rate does not constitute the minimal energy needed for the preservation of all physical functions, just as the organs' share in the basal metabolic rate cannot be equated with their minimal demand. Thus, the increased energy demand of the brain could also have been met by a reduced basal metabolic rate of all organs without the need for their reduction in size. Additionally, the authors do not consider Aiello and Wheeler's basic assumption, namely, that the metabolic rate of organs changes in relation to their size, as proven at this point.

The relevance of Aiello and Wheeler's model calculation is, after Henneberg (*ibid.* 213), difficult to evaluate, since the base data is also derived from models, such as those of a typical primate or human, and, thus, does not include the full range of possible variations. Katherine Milton notes (*ibid.* 215) that different segments of the intestines can easily adapt to changed conditions in connection with the food supply during one lifetime. The gastro-intestinal system of humans from non-industrialized societies, which has to process less easily digestible food, is distinctly bigger than assumed in Aiello and Wheeler's model. To conclude, the question whether the augmented demand of energy for brain growth during the course of human evolution was indeed compensated by a reduction of the gastro-intestinal tract, has to remain open. The fact that such a reduction was primarily facilitated by more easily digestible and high-energy food, which was obtained through the use of tools and an enlarged perception of the environment, highlights the possibility of reciprocative intensification in the co-evolution of the brain and object behavior.

Anatomy of the Brain and Neuropsychology

The absolute and relative increase in brain volume is a distinct but only quantitative development in the evolution of the human brain. Studies on natural and artificial endocranial casts of fossil hominids also try to trace changes in the relative size of partial regions of the brain, which possibly resulted in qualitative consequences. While the *Bulbus olfactorius*, which processes olfactory signals, was reduced in relative size, the cerebellum and especially the neocortex underwent a distinct increase in relative size (Eccles 1993: 87). However, Dean Falk notes (1980: 98–99) that, while the human neocortex is approximately three times the size of that assumed for a non-human primate of the same size, its observed volume is not significantly larger than the expected volume for human brain size. The increase in brain and neocortex volume obviously occurred at the same time. Human encephalization is interpreted as the result of an increase in postnatal brain growth (*ibid.* 100).

An increase in brain development after birth is also suggested by studies on the Mojokerto child (Perning 1) from Java (Coqueuniot et al. 2004), dated to ca. 1.8 million years before present. While macaques exhibit about 70% of their adult brain volume at birth, primates are born with 40% and humans with only 25% of their respective average adult brain size. During the first year of life, the human brain grows to 50% of its adult size; in a 10-year-old is has reached an average of 95%. The brain of the great apes, by contrast, already exhibits 80% of its future volume after the first year of life. The *Homo erectus* child from Mojokerto, which was estimated to be about one year old, possesses a calculated endocranial volume of 72–84% compared to an adult *Homo erectus* – a percentage that still lies well within the range of modern primates. Brain growth that more or less occurs after birth also has consequences for the development of cognitive capabilities: the development of the brain and its neural structures is increasingly subjected to influences derived from increased interaction with the environment, which during the course of human evolution was gradually enriched by cultural elements. In this, Coqueuniot et al. (2004) see the possible precondition for the evolution of spoken language; nevertheless, other brain functions and structures may also have changed with the extended interaction with the environment during the growth phase.

Neuropsychological studies have shown that different areas of the brain are responsible for specific functions. Animal experiments demonstrate the importance of the phylogenetically older parts of the brain, such as the limbic system or the hypothalamus, for emotional behavior. The functional differentiation of the cerebral cortex in contemporary humans is conveyed by studies on brain function failure, either congenital or acquired through disease, accidents, or surgery, as well as specific experiments with healthy test persons. By linking locally circumscribed brain lesions to psychical impairments or specific activation patterns associated with certain activities in healthy test persons, psychical-physical contexts can be derived. While new imaging techniques, such as computer and magnetic resonance imaging, can accurately pinpoint the localization of specific lesions, the association of psychical functions with clearly circumscribed regions of the brain has to remain cursory, since the lesions themselves often differ considerably in their individual extent and history (Sturm and Hatje 2002: 2–20).

So far, neuropsychological studies have shown a – possibly gender-related – functional asymmetry of the cerebral hemispheres, which can also correspond anatomically to a more pronounced left-sided development of the Wernicke and Broca language areas (Hartje 2002). While lesions of Broca's area, located in the posterior region of the parietal lobe, primarily affect pronunciation capabilities, damage to Wernicke's area, situated in the posterior region of the parietal and the anterior region of the temporal lobe, will result in impaired language comprehension (Huber et al. 2002). The term apraxia describes a defective selection of locomotive elements or their implementation in the wrong context or sequence. Its ideomotor variation occurs when the language-dominant hemisphere is damaged; the results affect the facial muscles as well as movements of the extremities on both sides. A lesion causing the ideatoric variant will be located in the temporo-parietal region of the language-dominant hemisphere. This variant constitutes a conceptual dysfunction and affects the sequential organization of movements in the purposeful interaction with objects (Poeck 2002).

The visual perception of optical information transmitted by the optic nerve takes place in the occipital lobe. The perception of objects is achieved in three stages: After the initial differentiation of the coherent object from other objects and the background, typical features of this momentary perception have to be filtered out and connected with the semantic memory, which resides in the basal temporal lobe. The final denomination of an object is obviously only possible if the knowledge of this object's significance can be activated. All three stages appear to be organized independently of each other (Goldenberg 2002). The perception of space, which is located in different regions of the frontal and occipital regions of primarily the right hemisphere, has to be differentiated from spatial cognition, which includes mental manipulations of space, such as rotation, mirror-imaging, or changes in scale, and is situated in the parietal and parieto-occipital regions of both hemispheres, as well as the so far not exactly localized spatial-constructive capability to assemble a shape from individual elements and the capability for spatial-topographical orientation (Kerkhoff 2002). Auditory perception and the comprehension of meaningful environmental noises and spoken word units are primarily located in the temporal lobes of both hemispheres; lesions can affect the perception of noises and words independently from each other (Engelien 2002).

The main seat of the so-called "executive functions," which are especially developed in humans, is, besides other minor cortical and sub-cortical regions, the prefrontal cerebral cortex. This term subsumes different cognitive processes, such as problem solving, categorization, mental planning, and the initiation and suppression of actions. Generally, the functions of the frontal brain are viewed as the most accomplished integrative achievements of humans; their explanation has been the focus of several cognitive models, which, however, have remained rather generalized and abstract. The prefrontal cortex includes areas that experienced different phylogenetic developments and seem to be part of anatomically separate cortico-subcortical networks (Karnath and Sturm 2002). Thus, from a phylogenetic perspective the integration of different partial functions and different anatomical and neurological sub-areas into one class of functions, which is located in a single area of the brain, has to be rejected.

The phylogenetic importance of the connection between psychical and, especially, advanced cognitive capabilities and certain regions of the brain noted in modern humans is by no means unambiguous. Impairments of reading, writing, and arithmetic capabilities (alexia, agraphia, and acalculia, respectively) caused by brain lesions demonstrate that new functions, which cannot be specifically fixed phylogenetically, can be integrated into existing functional areas of the brain through extension or redesignation. This conclusion is supported by the fact that the functions of damaged brain regions can be taken over by others. The underlying reasons may be structural; be it that a partial neuronal system is still able to execute the functions of the whole system (redundancy model), or that a specific function is controlled by multiple brain regions (multiple control model). However, the slow recovery of damaged functions rather suggests dynamic reorganization models. The model of functional substitution proposes that neuronal subsystems can over time assume the responsibilities of other, damaged subsystems; thus, while a task is not executed in an identical manner, the functional result still stays the same. The plasticity model, by contrast, is based on the generation of nerve cells from adjacent, undamaged tissue. Training and practice will not only lead to a considerable expansion of healthy regions, but also result in the regeneration of damaged areas (Hartje and Sturm 2002: 45–50). Based on these observations and models, the deduction of specific functions for different brain regions remains a hypothesis to be used cautiously.

When comparing an average primate brain, theoretically enlarged to human size, with that of a real modern human, differences of sometimes considerable dimensions can be observed in the individual cerebral cortex regions (Deacon 1994a: 123). While the areas responsible for processing auditory input, located in the superior part of the temporal lobe, are slightly bigger than expected for modern humans, it is the area of the prefrontal cortex that is especially noteworthy, since it is twice the size assumed for a typical primate. Liebermann et al. (2002) ascribe the relative increase in size of the temporal and frontal lobes of the brain to two autapomorph modern human features: the spherical brain case and the recessed face. After Falk et al. (2000), this increase is already visible to some extent in the morphology of *Australopithecus afarensis*, though not in the robust australopithecines or paranthropines. Among other functions, this part of the brain is responsible for the planning and organization of actions through the setting of objectives and decision-making. Other regions of the cerebral cortex, such as the premotor, somato-sensory, and visual cortex, display size values much lower than expected; the relative percentage of the premotor cortex differed most notably, with a reduction to 35% of the expected size. Detail studies of small cortex areas show, however, a distinct enlargement of the Brodmann area 6, which appears to be responsible for the control of complex motor actions that are crucial in the use of objects, compared to primates (Eccles 1993: 119). Nevertheless, Eccles concludes (*ibid.* 87): “The evolutionary development of the brains seems to be quantitative rather than qualitative. This even applies to the cerebral cortex, whose histological structure remains largely unchanged.”

Of special interest to the study of changes in the human brain are two brain areas that are connected with language formation and language perception; they are considered especially important for the evolution of language capability and, by consequence, of specifically human cognition. Broca's area, which controls vocalization, is situated in the lower posterior region of the parietal lobe; in humans, its layout is asymmetrical, with the part located in the left hemisphere generally larger. Wernicke's area in the lower part of the parietal and the upper region of the temporal lobe is situated between the various centers for sensory input, such as seeing, hearing, and feeling. It is responsible for the naming of objects and the perception of language, as well as probably for associations that span different brain regions. In the modern great apes, only small precursors of both language centers could be detected. However, in chimpanzees, bonobos, and gorillas, the Brodmann region 44 of Broca's area, which is of crucial importance for the production of language, displays an asymmetry with a dominating left hemisphere, similar to that in humans. This asymmetry can be associated with the production of gestures and accompanying vocalization and may constitute the point of origin of the evolution of language systems in humans (Cantalupo and Hopkins 2001).

Owing to the insufficient preservation of fossil finds, endocranial casts have not permitted the evaluation of the Broca and Wernicke areas in *Australopithecus afarensis* to this date (Tobias 1995). Later *Australopithecus africanus* individuals from Sterkfontein and Makapansgat generally display a bulge in the region of Broca's area, but – with the exception of one individual – remain flat in the region of Wernicke's area. The endocranial cast of an *Australopithecus robustus* from the South-African site of Swartkrans also possibly exhibits a bulge in the region of Wernicke's area; but it is only with *Homo habilis* that Philipp Tobias (1987; 1995) observes a distinct bulge in both brain regions. Owing to the different configurations of the Broca and Wernicke areas, Tobias (1995: 42) reconstructs a hypothetical *Australopithecus robustus* who possibly used vocalization as a means of communication, if only infrequently. *Homo habilis* is assumed to have possessed the neural structures on which language is based (Wilkins and Wakefield 1995); Tobias (1995) even assumes a form of spoken language as an essential part of the behavioral repertory of this species. He also theorizes that the evolution of language capability may have already taken place in the predecessors of the robust australopithecines and early *Homo* specimens.

The connection of the Broca and Wernicke areas with language formation and language perception is well established by clinical and pathological indicators as well as activity analysis through PET scans. Nevertheless, Wilkins and Wakefield (1995) remark that the interpretation of fossil endocranial casts contains more problems than simply proving the specific development of one brain region. For example, the centers may have evolved for purposes other than language, such as complex manipulative actions. Thus, the original function of these brain areas may have been substituted with or extended to language functions at a later, unknown date. Keeping this possible restriction in mind when studying endocranial casts, it can be stated that *Homo habilis* and probably also *Homo rudolfensis* possessed the neuronal basis for language from about one million years before present onwards. How exactly these brain areas were used, however, has to remain an open question. Generally, Deacon assumes (1994a: 123) that specifically human cognitive features do not stem from completely new structures, but rather from a reorganization of neuronal connections and an expansion or reduction of existing structures.

A Genetic Foundation of Language?

While from an anatomical perspective the evolution of the human brain is increasingly viewed as a process of general enlargement in size coupled with the reorganization of existing structures, lately genetic considerations have entered the field in order to explain individual cognitive areas, such as human language capability, independently from the general development. Based on a family study (Lai et al. 2001), the FOXP2 gene was identified as associated with language formation – through minute movements of the mouth and lower face – and language comprehension. Since such minute oro-facial movements are specifically human and do not appear in the pongids, Enard, Przeworski et al. (2002) studied mutations in this gene during the course of evolution by comparing humans, chimpanzees, gorillas, orangutans, macaques, and mice. The results demonstrate that after the split from the common evolutionary branch with chimpanzees, two mutations of amino acids occurred in humans, at least one of which could have had functional consequences for human language capabilities. Enard et al. estimate that this mutation took place during the last 200,000 years. It is, however, not clear whether the specifically human mutations in the FOXP2 gene are indeed directly related to the evolution of human language capabilities. While the differences between humans and primates were observed on the very gene responsible for speech impairments, they were still situated in different areas than the mutations in the speech-impaired individuals.

The Regulator Hypothesis: Increased Gene Activity in the Human Brain

Other than the targeted search for genes that cause specifically human behavior like language, there exist approaches that try to explain the general enlargement of the human brain and the specific mode of human thinking on a more generalized genetic basis. Since 98.7% of the genetic sequences of humans and chimpanzees are the same, Mary-Claire King and Allan Wilson developed the so-called regulator hypothesis (Enard, Khaitovich et al. 2002: 340) in 1975. It postulates that differences in gene activity – the rate at which the formation of RNA and proteins is triggered by genes – are responsible for differences in brain morphology, behavior, and cognition (Pennisi 2002: 233–35). New studies on blood, liver, and brain cells of humans, chimpanzees, orangutans, and mice now show that all areas – blood, liver, and brain – possess species-specific patterns of gene activity with quantitative and qualitative differences. But while within the primate group the qualitative (gene differences) and quantitative (amount of RNA and proteins produced) differences in liver, blood, and brain are balanced, the human and chimpanzee brain samples showed distinct differences. Compared to the qualitative variations, the quantitative differences in both RNA and protein production were up to six times higher in humans. It follows that the gene activity of the human brain increased tremendously during its evolution (Enard, Khaitovich et al. 2002: 340–42). How and when exactly this change occurred is still unclear.

7 The Evolution of Human Thinking between Phylogeny and Individual History: The Organization of Thought

Information on the functioning of the mind is as ambiguous as that on the anatomical, neurobiological, and genetic foundations of human thinking. Approaches to the organization of the human mind are primarily based on psychological research; while the different models may show individual ties with neuroanatomical research results, these connections are not explicitly investigated in detail (cf. Cela-Conde and Marty 1997).

During the first half of the twentieth century the Standard Social Science Model emerged, which summarily assumes a general, inherited intelligence and a mind rather malleable by different learning processes (Tooby and Cosmides 1992: 24–31), without specifically trying to explain its evolution. This model is elaborated upon in approaches centered on the learning process, such as Jean Piaget's step model of the ontogenetic evolution of intelligence, which will be discussed in a later chapter. Starting with the 1950s, and inspired by the emerging cognition sciences and information technologies, approaches to a modular structure of human thinking and attempts to explain its evolution arose from the fields of linguistics and developmental psychology.

Language as a Mental "Organ"

Based on his deliberations concerning the genesis of human language capability, Noam Chomsky was among the first to hypothesize that the human mind at birth is not a homogeneous and undifferentiated structure but rather a jigsaw puzzle of many different cognitive structures or mental organs with different properties and principles (Chomsky 1980). Analogous to other physical organs, such as an arm or the heart, Chomsky considers the basic structure and design of these mental systems as mostly predisposed by rules and representations. Just as in the individual development of the body, there exists a species-specific biological heritage that governs the mode and limits of the growth of mental units, such as language or the use of arithmetic systems. The final structure, as well as its integration into the system or the mind, is largely predetermined by a genetic program.

Learning, which constitutes the development of the mental organs, is defined by Chomsky as the growth of cognitive structures along genetically predefined paths, initiated and partially shaped by the environment. Just as humans possess the ability to see, so they carry with them an innate basic knowledge of, for example, language, which is then fine-tuned through experience.

This basic knowledge is, after the modular model, an innate mental structure and not to be confused with the independent ability to make use of this knowledge.

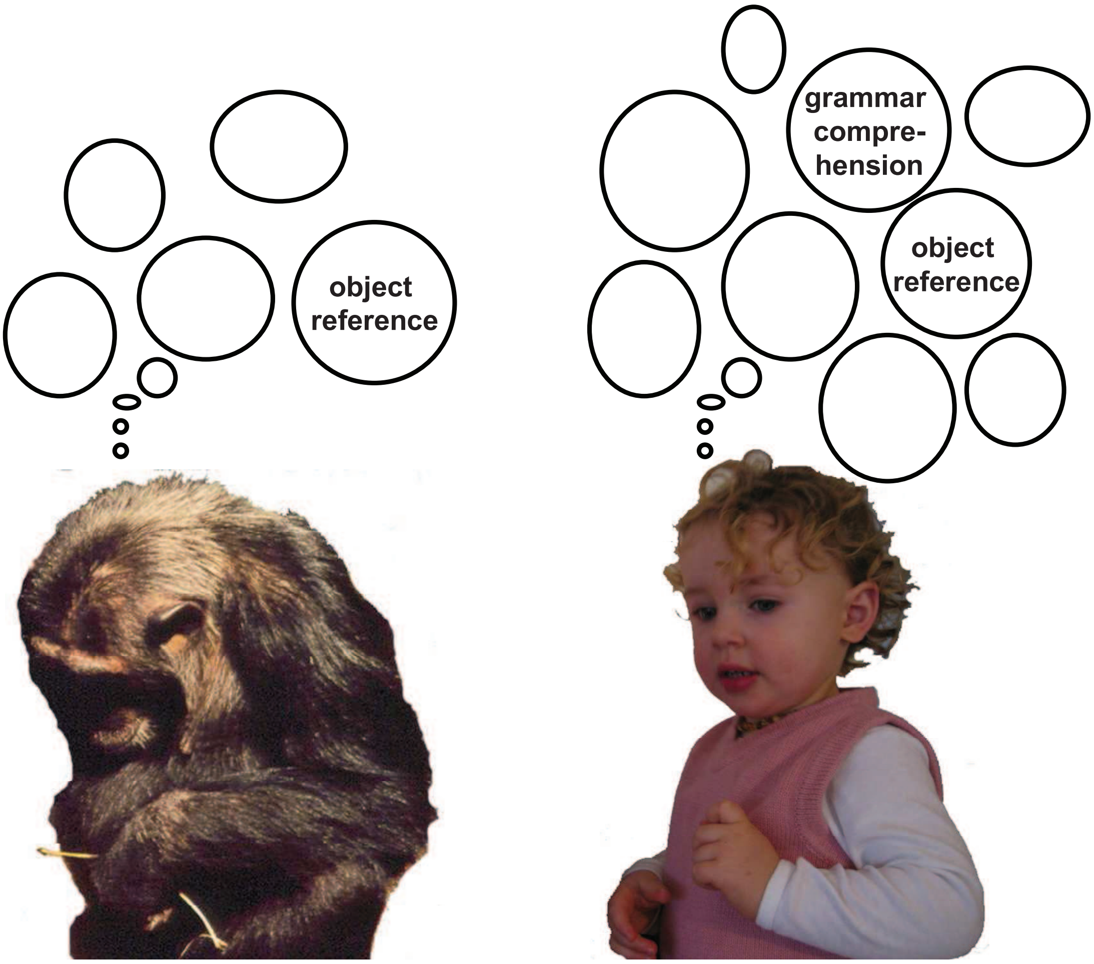


Fig. 5 The structure of the mind after Chomsky (1980), exhibiting innate cognitive structures with specific properties and principles. According to this model, humans – as opposed to the great apes – possess both modules necessary for language capability: a conceptual system of object reference and grammar comprehension.

Human language capability is structured, after Chomsky, into grammatical language comprehension on the one hand and a conceptual system on the other (fig. 5). This general system of object reference, which is crucial for the overall comprehension of the environment and does not constitute a special language capability by itself, is also common in the great apes and enables them to use elementary symbolic communication. By contrast, Chomsky recognizes the grammatical ability to identify and process language patterns as a universal and innate basic structure exclusive to humans. As a typical domain of the modular model, the grammatical comprehension of language involves diverse and complex mental structures, which develop under only minimal influence from the environment.

Multiple Intelligences

In extension of Noam Chomsky's linguistic approach, the developmental psychologist Howard Gardner postulates the existence of multiple mental capabilities or intelligences, which he characterizes as the ability to solve real problems and – based on the foundation of new knowledge – detect or create problems (Gardner 1991). It follows that, just as in the case of grammatical language capacities, other mental capabilities are innate as well. The flexible individual implementation is adaptable or modifiable by the natural or cultural environment as well as practice, so that different cultural circles can influence the specific focal points of the individual intelligences.

Gardner sees the basis for the identification of the different intelligence domains in their independence from other modules. He detects indicators of this independence in the isolated impairment of specific abilities after brain injuries, as well as the occurrence of widely varying emphases in the case of musical or mathematical prodigies or *idiots savants*. Additionally, he postulates that the modules possess fundamental operations or data processing mechanisms that are tailored to their individual perception components; language intelligence is differentiated into phonetics, syntax, semantics, and pragmatics, while musical intelligence is split into melody, rhythm, and timbre. The ontogenetic development of the individual capacities is supposed to be distinct from each other, but Gardner also does detect indicators of a phylogenetic evolution. Besides indicators of an autonomous capability glanced from experimental psychology and psychometry, Gardner postulates that the last indicator of human intelligence is found in its general openness to organization by means of cultural symbolic systems, such as words, numbers, shapes, gestures, and rituals or religious systems in the widest sense. On the basis of these indicators, he preliminarily postulates six different intelligences: linguistic, musical, logical-mathematical, spatial, physical-kinesthetic, and intra-/interpersonal (fig. 6).

Fig. 6 The organization of the human mind after Gardner (1991) with at least six independently evolved intelligence domains.

While Gardner characterizes the individual intelligences as units that develop independently from each other and can also be furthered independently, he still considers them to be interactive and building on each other. He rejects Jerry A. Fodor's assumption (1983) of a central unit furnished with general capabilities, such as perception and memory, that bundles information from different domains, such as language and visual or musical analysis, in order to formulate hypotheses, make decisions, or solve problems, as mere speculation. In contrast to his domains, which can be studied through experiments, he views a central unit as too cross-linked to be recorded empirically. Nevertheless, he views certain cognitive operations, if not spanning different domains, at least as occurring throughout different modules. The phenomenon of 'common sense,' i.e., the ability to solve problems intuitively, rapidly, and in a sometimes unexpectedly precise manner, occurs, after Gardner, primarily in the interpersonal, physical, and spatial domains. Originality, the ability to develop important, novel mental products, is frequently observed in children; in adult individuals, even talented ones, it is mostly restricted to one module. The metaphoric capacity to perceive and find analogies searches for patterns in different domains and then establishes connections between them. Metaphoric thinking is very common in children of preschool age; later in life it is often relegated to the background. While originality and imagery are primarily displayed during childhood, a final ability to synthesize – wisdom – is generally associated with advanced age. Following Gardner, these few multi-domain operations are not sufficient to postulate the existence of a central intelligence unit.

After Gardner, human thinking is based on genetics and shaped by culture. While he does not subscribe to the scenario of a phylogenetic evolution of linguistic, musical, and logical-mathematical intelligence, he considers the personal intelligences to be the result of closer and extended mother–child relationships and communal hunting of boys and men. The most detailed statements are to be derived from tools in use, which, after Gardner, constitute the common products of spatial and physical-kinesthetic intelligence, and the use of which requires three prerequisites: sensorimotor maturity, the play with objects, and stimulation by the perception that the environment can be manipulated. The purposeful invention of new tools, i.e., other than through trial and error or improvisation, additionally requires, according to Gardner, logical-mathematical intelligence in order to perceive the given problem and to establish theories about necessary actions and minimum expectations of the result. While lower primates use tools only rarely and almost never in an inventive manner, simple tools are common among the higher primates, especially chimpanzees. Although *Homo habilis* invented the cutting edge in stone tools, in a more general sense he never surpassed the capabilities of his predecessors. And while bifaces allowed for more precise and powerful cutting among *Homo erectus*, the more than one million years that passed between the appearance of these two species do not show any other progress, after Gardner. It is among Neandertals that he sees the first indicators of symbolic behavior in burials, and he acknowledges their use of habitations with functionally differentiated areas, fire, and big game hunting. The explosion of tool behavior, however, which also included new symbolic capacities, more precise tools, tools to manufacture other tools, a great variety of raw materials used, and the use of different tools for different purposes, he associates only with the appearance of modern man, 40,000 years before present (*ibid.* 201–2).

Cognition as a Set of Highly Specialized Adaptations

While Howard Gardner's model of multiple intelligences was primarily inspired by studies on aptitudes in modern humans and developed as a counter theory to the hypothesis of a general intelligence on the individual level, John Tooby and Leda Cosmides (1992) arrive at their model of different mental competences via evolutionary psychology on the population level. In their opinion, cognition can be equated with the processing of information, the problem solving mechanisms of which are organized functionally and evolved through selection. Thus, the cognitive structures of the human brain have to be viewed as biological adaptations that were selected according to their possible use in the solution of permanent problems among the predecessors of modern humans.

The great and typically human mental flexibility is explained by Tooby and Cosmides not as an arbitrary variability or absence of limits in a system that simply spans domains; rather, increasing degrees of freedom within the system, or new dimensions of possible variations, exponentially increase the number of alternative possibilities, so that the existence of a general intelligence unit would quickly lead to problems during the process of decision-making. If the range of situations that have to be processed by a cognitive mechanism is very wide, these situations will only exhibit few recurring characteristics. Thus, the possibility to adapt the mechanism to the situation lessens, which consequently reduces the number of given problem-solving strategies. If, however, the problem areas were narrowed down, the number of possible problem-solving strategies would increase. Additionally, the flexibility in Tooby and Cosmides' model can be increased by single, domain-spanning mechanisms, such as learning.

Tooby and Cosmides employ "evolutionary functional analysis" (1992: 73–77) to identify biologically adapted information processing mechanisms. The determination of an adaptive goal and its relevant constant environmental conditions is followed by the description of the organization of recurring characteristics of an organism, which together then form an (expected) adaptation (e.g., the eye). Afterwards, the result is rated as to how successful a mechanism is in achieving an adaptive goal or biologically relevant results under the given environmental circumstances. Tooby and Cosmides summarize the results of their method as follows (1992: 74): "The better the mechanism performs, the more likely it is that one has identified adaptation." Several cognitive mechanisms and the psychological phenomena grounded therein, such as language acquisition, grammar, mimic expressions of emotions, the selection of mates, or the incest taboo, have been identified as adaptations by evolutionary function analysis. Nevertheless, the method itself, as well as its results, remain controversial, owing to a number of basic assumptions that cannot easily be refined (see, e.g., Gould and Lewontin 1979).

From their model of a modular organization of thinking, Tooby and Cosmides derive a new cultural model, according to which biologically founded mechanisms function as triggers for the development of a behavior during ontogenesis, which then obtains its specific cultural characteristics through environmental influences. Consequently, human culture is not indefinitely variable and freely transmittable, but is primarily caused by the highly specialized cognitive structure – the meta-cultural framework – and local, temporal, and ecological factors. This evoked, adaptive culture is supplemented by a smaller percentage of transmitted culture. Thus, culture does not generate and reproduce itself, but is primarily based on numerous specialized mental adaptations that make humans capable of culture. Cultural change is caused by new external circumstances that lead to the activation of domain-specific cognitive mechanisms, thereby generating new views and purposes. The new ideas are more appealing in relation to the new circumstances and therefore spread, while the old cultural beliefs are increasingly rejected.

Fig. 7 Specialized intelligence domains as biologically adapted information processing mechanisms: The cognition model after Tooby and Cosmides (1992).

Steven Pinker (1994) recognizes this meta-culture, which is rooted in the various assumed domains, such as intuitive mechanical, biological, and psychological comprehension, an understanding of numbers, mental topographical maps, a feeling for rights and obligations, and a sense of family ties, to be equally responsible for human language capabilities. While Chomsky does not specify the phylogenetic origin of the “mental organ” language, Pinker defines human language capacity and its universal grammatical ability as an instinct acquired during evolution. This instinct is supposed to be the basis for domain-specific but universal learning mechanisms, parallel to the other mental modules. The evolution of the language domain occurred, after Pinker, through the selection of the speakers that were easiest to decode and the listeners that were able to decode utterances better than others. He assumes the first indicators of this adaptation to have appeared maybe as early as shortly after the split of the chimpanzee and hominid lines, 5–7 million years ago, and independently from the evolution of symbolic capacities, such as those exhibited in art or religious behavior (*ibid.* 352).

Language as the Foundation of Human Cognition?

Other than Chomsky and Pinker, Derek Bickerton (1995) does not view human language capacity or a universal grammar as one domain amongst others, but rather as the phylogenetic root of specifically human thinking. However, he does not see human cognition as divided into separate independent domains but as the further development of a central consciousness. Following Euan McPhail (1982), Bickerton recognizes only two levels of intelligence in animals (1995; fig. 8).

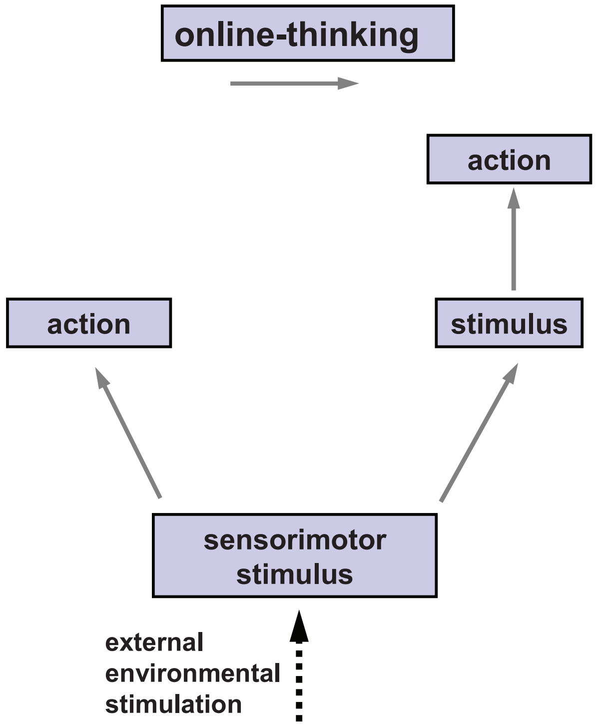


Fig. 8 The cognition model after Bickerton (1995) A: Thinking in animals is based exclusively on sensorimotor stimuli and tied to a direct context of action.

Thinking without explicit external stimuli (offline-thinking) is a completely different level of intelligence that is found only in humans (fig. 9).

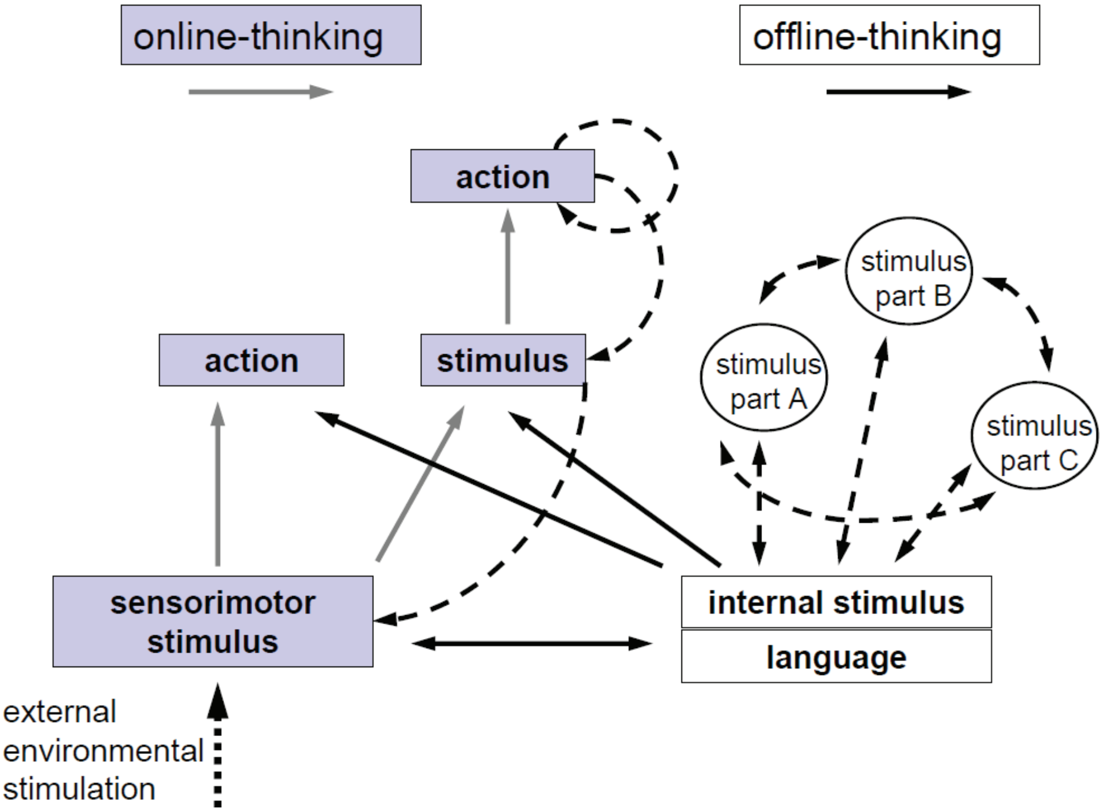


Fig. 9 The cognitive model after Bickerton (1995) B: In humans, online-thinking, which also occurs in animals, is complemented by offline-thinking, which is based on language and can occur without a concrete external stimulus. Language permits mental divisions, connections, and reflections of problems that are not subject to a direct context of action.

It allows for thinking without direct external cause and the anticipatory planning and rehearsal of behavior, so that learning can also take place outside an immediate stimulus situation. The extended human consciousness is aware of the basic sensorimotor consciousness; it is able to analyze and report upon it: humans are capable to reflect upon their actions. This extended part of the consciousness works primarily "offline," but can be short-circuited to the sensorimotor input via attention, so that the action and the reflection on its why and how can happen simultaneously. Depending on the significance of the situation that is experienced by an individual, the attention can be shifted between the basic consciousness, which analyzes the relationship between the organism and the surrounding world, and the extended, reflecting consciousness. In both forms of consciousness, processes can happen parallel and "unconsciously," but attention can be focused only on one, either external or internal, at a time. While the basic, animal consciousness creates a "state of brain" from which reactions result, the reflecting, human consciousness forms a “state of mind” (*ibid.* 150), which is dependent on self-perception and self-assessment and influenced by individual experiences not necessarily connected to the actual situation.

Since learning by offline-thinking has become independent from external stimuli or immediate observations, the things to be learned can be divided into more abstract components, which then later can be reassembled and reused in different situations. Theoretically, offline-thinking would lead to faster environmental adaptation via manipulation of the environment in a way that would benefit the manipulators. However, Bickerton does not find indications of such manipulations in animals or any human predecessors prior to the Neandertals; a fact that he attributes to the missing foundation of offline-thinking – language (*ibid.* 99–100).

Bickerton defines “language” as a representational system and a species-specific phenomenon based on biological foundations that stores information, executes thinking processes, and can *also* be used for communication purposes. Like offline-thinking, language requires brain cells that can perform without external input but also function without external output in form of motor action. After Bickerton, the evolution of language and offline-thinking began with the development of a proto-language, that is, single symbols, such as words or gestures, which in the beginning could not be connected or only in a limited way, without grammatical structure. Thus, language was initially selected not as a representational system but as a means of communication. It was only after abstract concepts for things or actions had reached a certain critical mass that a change in the neuronal network enabled the reassembly of individual symbols into infinitely variable chains of thought outside an external context; language could emerge as a representational system and, thus, offer the free space for the evolution of offline-thinking.

The evolution of offline-thinking and, in the following, a reflecting consciousness was, after Bickerton, only possible after the emergence of a structured language from the accumulation of concepts that constituted proto-language. Animal communication systems are closed, i.e., not arbitrarily expandable signal systems that express the immediate situation of the sender or try to influence the behavior of the recipient. They typically do not include combinations of units of communication, such as systematic relationships (e.g., screwdriver – tool as subcategory and topic, respectively), nor are they gradual, that is, e.g., the frequency of alarm calls does not increase with the appearance of more than just one predator. Proto-language, an intermediate stage between animal communication systems and language, combines only a restricted number of syllables and words to form expressions, which, in turn, can only be interpreted in a limited manner. Its elements only relate to real categories; structural or grammatical symbols, such as conjunctions (but, and, because) are missing. Under adequate training conditions, chimpanzees, gorillas, orangutans, bonobos, sea lions, dolphins, and grey parrots all proved able to acquire symbols and connect them to form simple expressions, such as they appear in contemporary proto-language during early childhood or in pidgin languages.

The fact that human predecessors, from *Homo erectus* to the Neandertals, also communicated on the level of proto-language would explain, after Bickerton, why the human brain grew in size during the course of human evolution without a parallel, accompanying increase in intelligence. He views the enlargement of the brain as connected to the storage of an increasing number of pieces of information that could only be connected to each other in limited ways. It was only the accumulation of a critical mass of information or symbols that finally caused the "development from protolanguage to true language, via the emergence of syntax, which was a catastrophic event, occurring within the first few generations of the species *Homo sapiens sapiens*" (*ibid.* 69). Bickerton detects no intermediate stages, neither in the archaeological nor the linguistic context. It was a structural change that finally freed the regions of the brain developed for the use of proto-language, the performance of which does not result in immediate action, for structural, grammatical language and ensuing offline-thinking. This structural change can be detected in the archaeological remains of our ancestors, which, after Bickerton, show an explosion of intelligent behavior with the appearance of modern humans, after a time of relative stagnation that lasted from *Homo habilis* to *Homo erectus*.

Consciousness as Executive Central Authority

Instead of phylogenetically separately evolved modules in the human mind, as postulated by the linguists Chomsky and Pinker and the developmental psychologists Gardner, Tooby, and Cosmides, Merlin Donald (2001) only acknowledges, similar to Derek Bickerton, the existence of functional networks based on individual development and a more general aspect that forms the basis of all conscious mental operations: consciousness. In contrast to Bickerton, Donald views the extended human consciousness not as the result of symbolic thinking and language but as its precondition. While already Jerry Fodor (1983) interpreted consciousness as a domain-spanning central unit of the brain, but only acknowledged its passive reflection of the function executed by the subconscious modules, Donald (2001) also assumes an active, executive role of the consciousness, namely, the superordinate, independent overview and control of individual brain functions. The orientation of the "self" in time and physical as well as social space is controlled, maintained, or adapted, so that the object is able to identify itself and its position on an autobiographical level of memory. The core function of the consciousness is, thus, the continuous updating of knowledge.

Through active concentration and selective focusing, the consciousness achieves the optimization of the cognitive system. Concentration leads to the appearance of a temporal functional network in the brain; frequent repetitions then result in the establishment of permanent structures. The conscious control of repetitive actions thus leads to the automation of whole chains of actions, such as driving a car, playing the piano, or speaking, where consciousness subsequently only interferes under exceptional circumstances. Thus, automated behavior is not unconscious behavior but was consciously learned and retrospectively automated through everyday use.

In contrast to Bickerton (1995), Donald (2001) detects the accumulation of criteria for the existence of consciousness already in primates, and especially the great apes. These criteria include an autonomous model of the world; the perception of complex objects or events as units; flexible and adaptive behavior; mental autonomy, which allows for a reaction that is independent from external stimuli and can be delayed; the ability to maintain individual relationships; the possible change of perspective to empathize with the thinking of other individuals. This extended capability of conscious reflection, control, and its ensuing behavior constitutes the phylogenetic foundation of human beings. The specifically human adaptation of the coordinative and controlling function of consciousness is demonstrated by a whole bundle of superordinate behaviors:

1. Monitoring of success or failure resulting from own actions;
2. Divided attention, which allows the execution of several tasks at the same time;
3. Deliberate self-memory;
4. Internal sequence (e.g., of symbols, such as in language);
5. Self-perception as the subject in relation to objects;
6. Practicing of actions, with reflection on past actions and improvements on future ones;
7. Imitation skills using the whole body;
8. Imagining the thoughts of others as the basis for own actions;
9. Teaching, which requires the mutual imagining of the opposites' thoughts, i.e., the sharing of thoughts;
10. Conscious and directed signals, such as gestures;
11. Symbols;
12. Accumulation of complex hierarchical proficiencies, like talking or driving a car, that mostly proceed automatically and are just monitored by consciousness (Donald 2001: 132–46).

After Donald, the special conscious performances of humans are based on a three-phase system of consciousness, which is also fully developed in some primates and enables an episodic consciousness in these species (fig. 10). The first phase comprises the selective bundling of perceptions into units, caused by external stimuli, so that objects or events can be perceived as distinct patterns. The spatial and temporal extent of the bundling process leads to an expansion of the consciously perceived world, in which concepts can be developed. In the second phase of consciousness, the short-term control of actions forms the basis of a delayed reaction to stimuli and, thus, of a commencing autonomy of the subject from the environment. This conscious control can either suppress or reinforce actions, which means that limited resources can be used in a more flexible manner. The third phase is characterized by the medium- and long-term control of actions. Whole chains of actions can be controlled; actions do not need to be triggered by external stimuli anymore but can be initiated consciously – the monitoring of actions becomes possible.

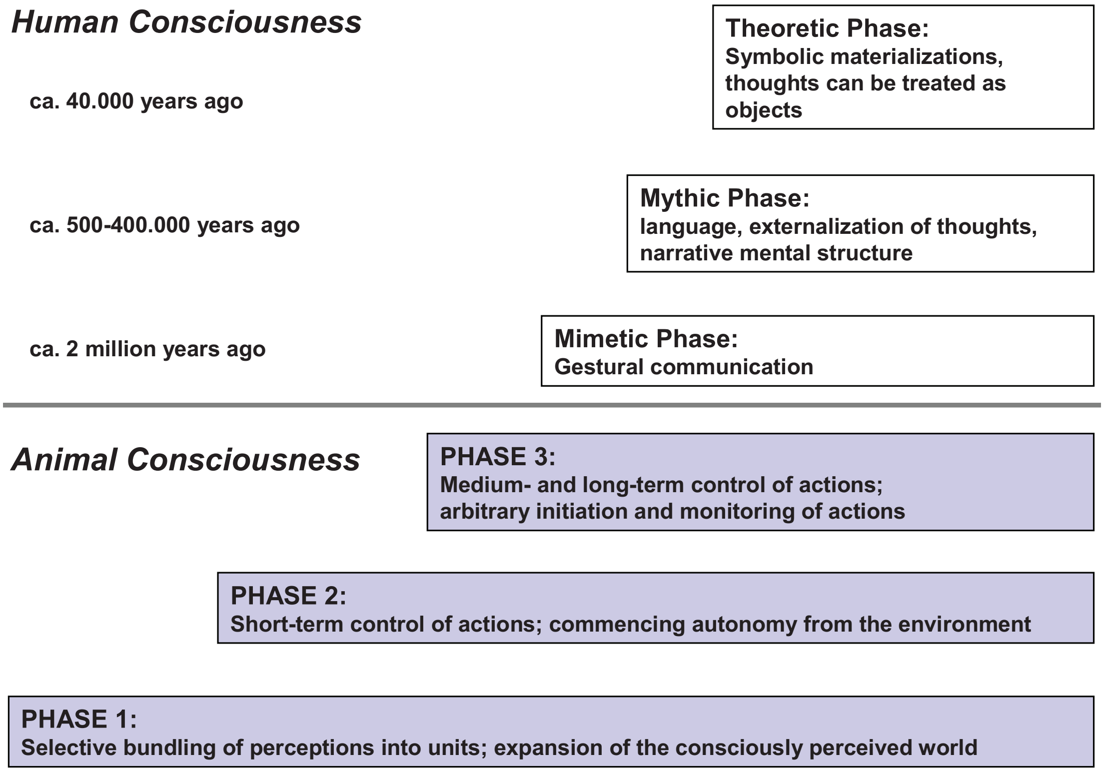


Fig. 10 The evolution of human consciousness after Donald (2001)

In addition to these three phases of consciousness, humans are, after Donald, distinctly specialized for executive functions (see paragraph on “Brain Anatomy and Neuropsychology”). In the course of – exclusively – human cognitive evolution he identifies a further three phases; it is the new form of cognition, which is shared among several individuals – i.e., culture – that creates a new reality, parallel to the natural environment and, as such, a new setting for this development. The first, “mimetic,” phase after Donald (2001: 262–74) is centered on miming or imitative skills, which enable, via the conscious execution of actions, the use of deliberate body language, precise imitation, and gestures. Mimetic communication and the social bonds and conventionality it promotes are necessary pre-adaptations for language. In order to communicate consciously, e.g., through gestures, several motor action areas have to be controlled, reflected, and modified over the span of several domains. Attention is focused not only on external events, but is increasingly shifted inwards towards the subject’s actions. Brain regions that perform executive tasks, such as the prefrontal cerebral cortex, expand during the course of evolution. This does not constitute a fundamental qualitative innovation in brain anatomy, after Donald, but is merely the result of a progressive differentiation of the primate brain. In a cognitive context, the mimetic phase is characterized by an increasingly precise control of body movements, which influences communication as well as object use and tool production.

Language, the main characteristic of the second, “mythic,” phase of development after Donald (*ibid.* 274–300), is based on the cognitive and cultural achievements of the mimetic phase. Its development can be visualized as, at first, vocal additions to vague mimetic expressions that became increasingly specific with the introduction of sounds with designated significance. In Donald’s opinion, language is the result of group adaptation and thus a cultural product. It is not the basis of consciousness, but only serves as an indicator system for the direction of attention or imagination. In order to develop language, the executive functions of the consciousness, such as differentiated temporal storage, the ability of multi-focal attention, and the enlargement of long-term memory that can be recalled instantaneously, have to be already expanded significantly. All consciously controllable brain functions that constitute the precondition for language are not restricted to language alone but span various domains. Language, however, also drastically changes conscious experience: it differentiates experiences, defines reality, and focuses attention. A narrative mental structure creates virtual worlds and changes the perception of experiences by allowing the focusing in on details and to view single events within a wider context. Language is not the cause of consciousness, but it serves as an intermediary or tool of meta-cognition. Through language, ideas can be externalized and viewed or modified like objects. They also can become partially independent from personal experience, which enables abstract belief as well as public discourse. With the development of language, thoughts are no longer isolated within an individual; they always form part of a cultural network that influences thinking. At the same time, the collective networks of knowledge within a culture are constantly changed by the verbal expression of the thoughts of individuals.

Symbols, which characterize the third, "theoretic," phase of human cognitive evolution after Donald (*ibid.* 305–20), mark a further step in externalization. Symbolic technology constitutes an extension of material culture and is specifically centered on thinking, remembering, and the imaging of reality; symbols can free the consciousness from biological memory systems. At the same time, ideas cannot only be externalized but also materialized symbolically, so that in fact they can be arranged, studied, organized, and compared like physical objects. This materialization leads to an expansion of mental operations: by separating thoughts from their previous context and arranging them in a different order, it can make the un-thinkable thinkable.

Donald places the transition to the mimetic phase with the first appearance of the species *Homo*, ca. 2 million years before present. Archaeological finds suggest a group-oriented lifestyle, where material and cognitive resources were shared. Cultural strategies of remembering and solving problems allowed, in combination with mimesis, the consolidation and refinement of numerous abilities. The mythic phase in human cognitive evolution begins, after Donald, with the appearance of archaic *Homo sapiens*, between 500,000–400,000 years before present, and reaches its climax around 125,000 years before present. In the archaeological context, this phase is represented by accumulations of aesthetically pleasing objects, the improvement of shelters, and the burial of the dead. Additionally, Donald includes – towards the end of this phase – personal ornaments; multi-piece objects and mountings; boats; complex dwellings; ritual, quasi-symbolic artifacts; and musical instruments. The spread of cultural achievements accelerated with language and oral culture. The third, theoretic, phase began, after Donald, 40,000 years before present with the appearance of symbols, which, via the conscious externalization of memory, allowed the storage of cultural knowledge independently from the achievements of individuals (*ibid.* 261–62). The exploitation of the cognitive potential of symbolic technology was a slow process: even after the development of writing in urban settlements, this new technology was only used as a mnemonic device or a means of keeping records. It was not until later that writing turned into an instrument of reflection (*ibid.* 306–8).

After Donald, culture is the crucial factor in the cognitive evolution of humans, since it constitutes a necessary precondition for the development of language. In contrast to non-cultural beings, cultural individuals do not act and think in isolation: culture is built from the collective cognitive activity of many brains. Cultural cognitive communities can be defined as networks of knowledge, emotions, and memories; language and symbols are not at the core of culture but only its byproducts. Culture does not only focus attention on certain areas and distracts it from others, it also influences the executive functions of the brain. Because of the neural plasticity of the human brain, special functional networks can be created to serve specific cultural tasks, such as writing and reading, for example; these networks influence our way of thinking. Besides the genes and the natural environment, deep cognitive acculturation is another important factor in the development of the brain – phylogenetically as well as individually.

While Gardner (1991) and, especially, Tooby and Cosmides (1992) do not consider individual development during life and, thus, the influence of learning processes and culture to be significant contributions to the organization of thinking, Donald’s model (2001) places them as of utmost importance in the building of neuronal networks. In contrast to the modular models, which have to be viewed as cognitivistic after Varela’s definition (1991), the approaches by Donald and – to a lesser degree – Bickerton (1995) can be interpreted as connectionistic, where cognitive patterns only develop during ontogenesis from undifferentiated neuronal subsystems under the influence of a central consciousness and individual external as well as cultural influences. One of the most influential models of ontogenetic development of human intelligence during the last decades will be presented in the following chapter.

8 The Evolution of Human Thinking as an Ontogenetic Problem

Although the research institute, founded in Geneva in the 1930s by Jean Piaget, is called the "Centre international d'Epistémologie génétique," its approach depends only to a lesser degree on genetics; its influences come from the fields of biology, sociology, linguistics, logics, and epistemology. The basis of the "theory of cognitive development" developed at this institution (Piaget 1985) primarily comes from psychological studies on the development of intelligence in children. Piaget's phase theory can be understood as the ontogenetic complement to Konrad Lorenz's phylogenetic hypotheses. Together they form the foundation of evolutionary epistemology, although the active, dynamic angle of Piaget's epistemological approach hardly finds use among researchers in this field.

The assumption, in a connectionistic manner, that mental and brain structures are not primarily phylogenetic and already fully formed at birth, but that interaction with the environment plays an important role in their development, introduces two possibilities. The empirical view is that cognition is grounded in objects and the environment itself. It is created by acts of perception that – systemized and coordinated within the subject – form an image of reality and build cognitive structures through repetition. Piaget contrasts this approach, which assumes a passive subject, with an active role of the subject in the gain of knowledge: to perceive objects, an individual has to act on them and transform them through motion, connection, analysis and reassembly into different states. Thus, cognition is the result of a process of constructions executed by an individual. For example, the knowledge about the permanence of objects, which is not perceived during the first few months of life, is experienced in a first step as dependent on actions by the subject, and is only later, after a process of decentration, perceived as independent from the subject. With the aid of self-regulation, physical experience, information, and the coordination of actions all build structures that enable cognition. It follows that cognition is neither inherent, nor are the basic structures, such as space, time, and causality, *a priori* given constants that are innate to the subject and completely preformed (Piaget 1985: 25–29).

Cognitive adaptation, i.e., the process that builds cognitive structures, is, in Piaget's opinion, comprised of two mechanisms, the balance of which changes according to age. His definition of assimilation implicates the incorporation of external elements or information into the existing structures of an organism. In order to form a cognitive process, assimilation is complemented by accommodation, a change in the receptive structures that is brought about by assimilated elements. If assimilation outweighs accommodation, object features are only considered in a way that benefits the current interests of the subject. The mode of thinking is egocentric, such as, for example, in symbol or fiction play. However, if accommodation outweighs assimilation, the subject characteristically adapts its structures to existing models, such as in realistic reproduction or imitation. Delayed or internalized imitation is the basis of figurative thinking. Cognitive behavior, by contrast, stems from an equilibrium between assimilation and accommodation *(ibid.* 32–36*).*

In Piaget's model of the development of intelligence in children, the interdependency of genetic predispositions and environmental circumstances leads to the development of cognitive structures during childhood by means of assimilation and accommodation. This development is divided into three consecutive stages. In the first, sensorimotor, stage, Piaget distinguishes a first phase up to an age of 7–9 months, which is centered on the subject's own body. During the second phase, up to an age of 1.5–2 years, practical intelligence is focused on objects and adapted to the conditions of space. Assimilation and accommodation are in equilibrium during the sensorimotor stage when practical problems that relate to the immediate surrounding space are dealt with (*ibid.* 37–41).

The second, concrete operational, stage after Piaget is divided into a preoperational phase up to an age of 7–8 years and a concrete operational phase up to 11–13 years. The preoperational period is marked by the recognition of a qualitative identity of objects that persists even after their alteration – a toy building block stays a toy building block even if it has been painted blue. Additionally, this phase displays the beginnings of the purposeful mental use of variables, so that, for example, the reduction in length of a string of clay after its compression can be anticipated. However, reversibility of operations – internalized actions or action plans – as well as the conservation of volume in transformations, i.e., that the string of clay is diminished overall but just becomes shorter and thicker, is not cogitable at this stage. The expansion of thinking to incorporate a further extension of space and to more than the immediate practical result leads to a distortion in favor of assimilation during the preoperational phase. Piaget considers the intake of information to be closely related to the object, i.e., egocentric, while accommodation is incomplete, because it is limited to conditions or figurative aspects of reality and does not incorporate conservation. During the preoperational phase, imagination remains reproductive and static (*ibid.* 38–59).

In the concrete operational phase of Piaget's stage model, children are assumed to be capable of abstracting qualities and consider them independently from other characteristics of an object. This enables them to execute concrete operations or action plans on objects: ordering things, lining them up, establishing relationships and classifications. After Piaget, the synthesis of such basic arrangements leads to the development of metric and numeric quantification (*ibid.* 78). In this phase, the perception of changes in conditions or variables as well as conservation – the string of clay that retains the same volume whether it is long and thin or short and thick – is possible. From this phase on, assimilation and accommodation affect conditions as well as transformations, so that now reversible actions an be generated. After Piaget, this change is caused by a cognitive process where the subject-centered intake of information is substituted by decentration, so that now the perspective of other subjects or the position of other objects can be taken. Children now possess reflective as well as anticipating imagination, which is the basis of the mental representation of all transformations (*ibid.* 38–59).

In the third, or formal operational stage after Piaget, structures are formed that enable the arrangement and coordination of actions, such as classifications of classifications or operations on operations. Besides simple abstractions derived directly from the object, which can be assimilated directly, the formal operational stage additionally allows abstractions derived from operations. During the course of this reflective abstraction, the characteristics of an action are extracted on a first level and then transferred to a second level, where the characteristics are reconstructed, submitted to additional thought processes, reflected, and reinforced through the operation itself. This opens the possibility of not only mentally acting out specific actions but also to develop superordinate meta-theories (*ibid.* 78–80). The beginning of the formal operational stage is assumed to take place between 12–16 years of age. Piaget does not consider the age range connected with the onset of the different stages of development to be completely fixed. Differences can occur from individual to individual, owing to environmental factors that can accelerate or slow down the process. The general sequence of the stages, however, is considered to be fixed, since they necessarily build on each other (*ibid.* 44).

A central but often neglected aspect of Piaget's theory is the active gain of knowledge. It states that learning is more than just the perception of the individual environment and its imaging in a neuronal network. Instead, the subject interacts deliberately with chosen objects, transforms them, and from this interaction builds new operational structures. Human thinking not only discovers reality but transforms and enriches it (*ibid.* 47).

As factors of cognitive development Piaget notes maturation and experience, which he subdivides into practice; tangible experience, which equals the simple process of abstracting objects and leads to a mental differentiation of characteristics; and logical-mathematical experience, which stems from the interaction with objects and equals reflective abstraction. Thus, experience is partially derived from the object and partially constructed within the subject. Further factors are the social environment of the subject as well as progressing self-regulation, which coordinates maturation, experience, and the influence of the social environment to form a consistent entirety (*ibid.* 62–68). Thus, the understanding of the interdependency of thickness and length of a string of clay during its transformation and the reversibility of the transformation process is not a problem of perception but depends on self-regulation. In this case, the coordination of the factors maturation, experience, and social environment leads to a new quality of reasoning thought: in addition to conditions, transformations now become conceivable (*ibid.* 74–75). It follows that the cognitive development of the individual after Piaget is neither a merely empirical process discovering an external reality, nor is it completely determined by genetics. Rather, it is implemented constructively, through the interaction of subject and object, in the active development of cognitive structures.

9 The Third Dimension: The Evolution of Human Thinking as Historical Problem

The influence of the environment on the evolution of human thinking has so far been subject to short treatments in the chapter on the organization of thinking and the discussion of ontogenetic development. Human environments differ markedly from those of most animals, because they were created to a large extent by our species itself. Other than animal environments, these actively designed human "worlds" possess historicity, which is the necessary basis for the formation of different groups or "cultures" and their continuation. Humans develop cognitive faculties not only along genetically predetermined lines or actively and reactively through individual interaction with the environment but also based on a foundation that is established by social groups and evolved historically and within a constantly changing, shifting, and growing framework.

Cumulative Cultural Evolution through Cultural Learning

The evolutionary psychologist Michael Tomasello (2002) agrees with the assumption that the beginnings of specifically human cognitive faculties stem from a genetic mutation that distinguishes us from all other contemporary species. In contrast to Noam Chomsky (1980), Howard Gardner (1991), John Tooby and Leda Cosmides (1989; 1992) and several others (cf. Barkow et al. 1992), who all promote the development of human cognition from different, independent modules that are supposed to have evolved from multiple genetic mutations, Tomasello (2002: 23–25) views most, if not all, species-specific human capabilities not as the direct result of specific mutations, but as evolved through historical and ontogenetic processes. He considers only one biologically inherited capability, namely that which enables the perception of members of the same species as intentionally acting beings, to be the source of the cultural transmission of abilities and knowledge and, thus, historical development (fig. 11).

Cultural-historical processes that build on the accumulation and conservation of collective inventiveness can happen in significantly shorter intervals than biological adaptations. This cumulative cultural development is caused, on the one hand, by the so-called ratchet effect, which enables a progressive building up of innovations and, thus, figuratively speaking, the collaboration of different individuals in the solution of a problem over a historical period of time, and, on the other hand, by interaction through dialog, where several individuals work simultaneously and interactively on the solution of a problem (*ibid.* 54). The conservation and further development of various innovations in different populations leads to sociogenesis, that is, the emergence of different cultural entities or groups.

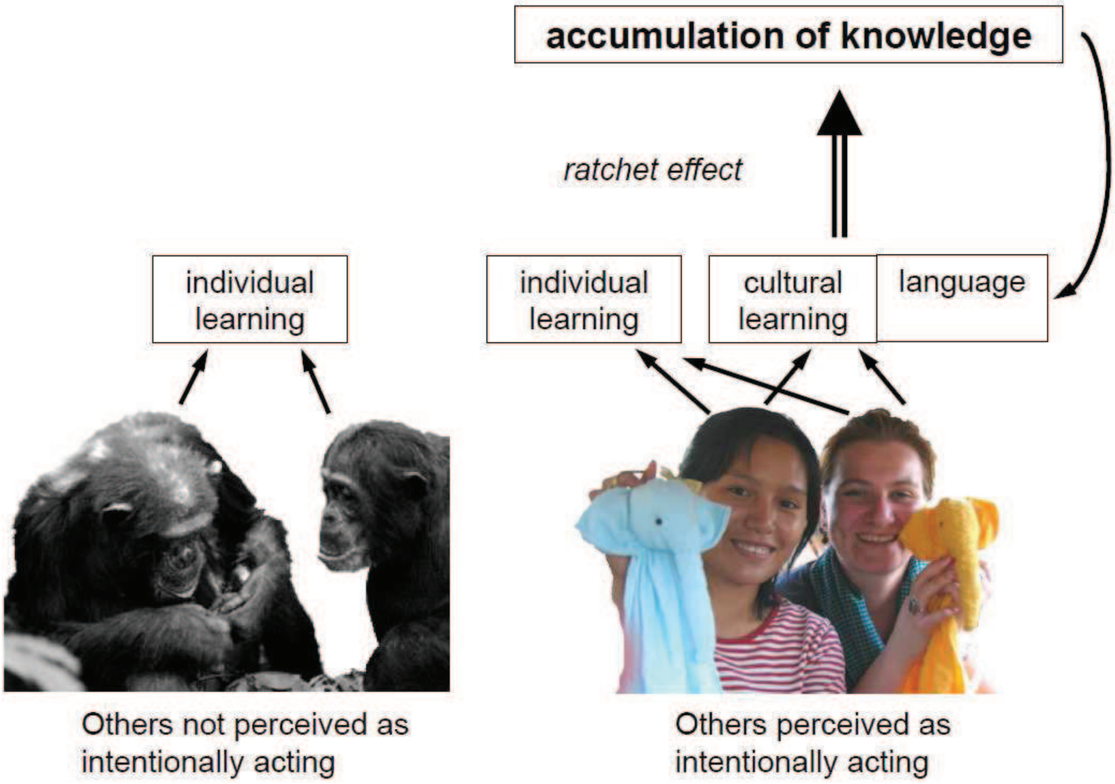


Fig. 11 The model of cognitive evolution after Tomasello (2002)

The accumulation of cultural innovations and adaptations is a historical process that is made up of many different individual developments. In turn, the development of an adult individual – a phenotype – is the result of an individual process that is based on its genetic make-up with influences from its physical and social environment. Thus, cumulative cultural development and individual developments or ontogeneses influence each other. Following the dual inheritance theory, both biological and cultural inheritance are responsible for the development of mature phenotypes in humans. The social or cultural environment is a source of influence in two important ways: first, as an environment for individual learning by means of objects, social interactions, typical learning experiences, and conclusions, and second – especially among humans – as a source of active, interceding education (*ibid.* 97–98). Human ontogenesis is characterized by intensive individual and cultural learning.

Mode of learning	Form of learning	Description
Individual learning: Individual forms of learning in a social context on the basis of orientation or events within the environment without the perception of others as intentional actors ⇒ no accumulation of knowledge.	**Physical contact with the learning situation**	Visiting of special environments with the group; different environments with different possible tasks or problem situations
	Stimulus increase	Intensified attention to stimuli from the environment through observed actions by others
	Imitation	Reproduction of the behavior of others without understanding of its process or effectiveness
	Emulation	Result-oriented learning through the example of others without understanding of the behavioral strategy
	Ontogenetic ritualization	Repetitive social interactions shape the behavior of those involved (e.g., communicative signals)
Cultural learning: Social forms of learning on the basis of the perception of others as intentional actors ⇒ accumulation of knowledge.	**Imitation**	Reproduction of the behavior of others with understanding of the behavioral strategy
	Teaching	Active instruction of the inexperienced by the experienced; attention is actively directed and focused

Table 4 Breakdown of forms of learning after Tomasello (2002)

These two modes of learning, which can be subdivided into different forms of learning (Table 4; *ibid.* 37, 40–47; see also Tomasello et al. 1987), are, after Tomasello, fundamentally different from each other. According to his developmental-psychological studies of learning among children and chimpanzees, primates only display individual forms of learning; cultural – and, thus, historically accumulating – forms like imitation and teaching are restricted to humans only. He views the perception of others as intentional actors, which is the result of a genetic mutation in the human lineage, as the basis of these cultural forms of learning.

Tool use and culture in chimpanzees are, according to Tomasello (*ibid.* 40–49), the result of individual learning, which is controlled by different local environments. Thus, the development of behavior is dependent on the environment. Evident learning by imitation only occurs among chimpanzees in close contact with humans; active instruction between two animals, that is, teaching, has only been observed very rarely and these instances are still under debate. The cultural forms of learning are influenced by certain types of social interaction during early ontogenesis: if infant chimpanzees grow up in a cultural environment similar to that of humans, the specific socialization of attention leads to the development of more human-like capabilities. However, even those animals that grew up under these exceptional circumstances only rarely develop attention actively. In their natural environment, chimpanzees cannot develop capabilities sufficient for human-like cultural actions or a cumulative cultural evolution.

The capability to perceive others as acting intentionally and to actively establish divided attention based on this fact is innate in humans. Still, it is only when children have developed an understanding of purposes as opposed to means through sensorimotor actions of their own that they are capable, by means of simulation, to transfer their own inner processes to other individuals similar to themselves and subsequently perceive them as intentional actors. This perception, after Tomasello, is developed in children as early as 9–12 months of age. Combined with the division of attention, it enables triadic behavior, that is, interaction within an interrelated triangle composed of the child, an adult person, and an object or event, which forms the basis of learning by imitation (*ibid.* 79–92).

Tomasello traces the specific potential for interactive learning and the cultural evolution it facilitates through the example of the ontogenetic development of language. This example clearly demonstrates the cognitive consequences of a biological change – the capability to perceive others as acting with a specific purpose in mind – with cultural ratchet effect. The perception of others as intentional actors in situations of shared attention allows the understanding of the communicative intention of others, as well as a reversal of roles in communication. Thus, the foundations are laid for the development of linguistic symbols as means of communication that actually can be understood intersubjectively. Without this perception, only simple signals can be used that do not allow more than the awareness of the own communicative role from an own inner perspective. Yet, human communication processes enable the experience of perspectives: depending on the viewpoint or situation, a rose can be a flower, a thorny plant, or a present (*ibid.* 128–29). Children thus not only have to learn the functional dimension of words but also the culture-specific intentional dimensions that correspond to these terms from different perspectives – that is, the conventions within which symbols or words are used. The same holds true for objects or actions: functionally, a brush is a brush, but cultural conventions dictate that a hair brush not be used as a shoe brush, a tooth brush, or a toilet brush.

Words are examples of typically human cultural representations of the environment that stem from divided attention and the urge to communicate about it. On the other hand, after Tomasello, primates internally only possess sensorimotor representations of the environment, such as classification, simple causal consequences, and image schemes. Public symbols shared within a group can again be re-classified, and cognitive perceptions themselves become objects of attention, contemplation, and mental manipulations (*ibid.* 149–52). Thus, more complex and abstract language constructions besides words, such as grammatical constructions, can be identified as symbolic units with their own content of significance.

Conflicting views expressed in a conversation, such as misunderstandings or differences, create meta-speech, the voicing of opinion about an expressed view. In order to dissolve such situations, the own thinking has to be viewed from the perspective of the dialog partner. The ability to talk about their own contemplations and problem-solving strategies enables metacognition and self-regulation in modern humans as early as 5–7 years of age. Both concepts allow the use of certain rules in the solution of problems, the repression of spontaneous action impulses, as well as meta-memory, for example in the form of planning strategies. Through actions with objects and interactions with people the individual collects implicit, procedural knowledge. The contemplation of actions or processes and the isolation of single, function-specific characteristics permit the reclassification of practical knowledge within a system of external, cultural representations. During this process, experiences can be synthesized and abstracted by means of systematization and categorization (*ibid.* 201–27). Language plays a triple role in Tomasello's model of the cumulative cultural evolution of human thinking. Firstly, as the external representation of the environment, language is a product of divided attention and the cultural development ensuing therefrom. Like other cultural products, it is subject to the ratchet effect and accumulates innovations. Secondly, language as a symbolic artifact can act as a means of reflection, where the objects, actions, and events, as well as different views and conventions it represents are mentally categorized, rearranged, and acted out. Their abstracted form and enlarged content permit language-based reflections to exceed reflections based on strictly sensorimotor representations. Thirdly, language is a tool that enables the purposeful division of attention and, thus, facilitates the transmission of cultural elements in the environment. Therefore, language as a cultural product accelerates the accumulation of knowledge.

Tomasello places the occurrence of the genetic mutation that enabled the perception of others as intentional actors somewhere between 6 and 0.2 million years before present; he assumes the development to be a rather short one (*ibid.* 13). In his view, this genetic mutation all at once allowed for the modern cognitive spectrum, which arose in its contemporary form out of a historical-cultural process.

A very different historical-cultural model of human thinking on the basis of biological changes emerges from the philosophical approach of Peter Sloterdijk, which is based on deliberations first voiced by Martin Heidegger. Here, the historical dimension is not established through a single mutation but rather the concurrence of several different factors of development.

The Domestication of Being

In all explanations of the human phenomenon, Peter Sloterdijk (2001) generally detects two directions of approach: on the one hand, the mainly philosophical attempt to understand the human being on the assumption that the being to be explained has always existed in its present form, and, on the other hand, the mainly scientific way of explaining human evolution, where the actual human nature is only considered in an unsatisfactory manner. He confronts these extreme approaches with a history of hominization where the hominization of pre-humans was paralleled by the evolution of our world as we know it. Sloterdijk argues that humans cannot be simply assumed in order to find their traces in pre-human stages of evolution, just as the world as it appears to contemporary humans cannot be considered immutable. Humanity's exceptional position is therefore tightly linked to an easing of environmental pressures and constitutes the result of various processes.

Sloterdijk characterizes the environments of different animal species as a surrounding sphere of biologically relevant circumstances and conditions. Within these relevance spheres, the actual openness to the world, that is, the part within which thinking and interaction take place, is confined to only a small section of the environment (*ibid.* 162). In contrast, contemporary humans have pierced the biologically relevant environmental sphere; they discover the world beyond the, for them, biologically significant aspects and create their own, new elements. Sloterdijk defines their basic situation as “Being-in-the-World” as opposed to the animal's “Possessing-Environment” (*ibid.* 173). Humans rise above the environment into a self-created and constantly expanding world. Between those two extremes of animal Possessing-Environment and modern human Being-in-the-World, Sloterdijk assumes spheres of intermediate worlds that emerged during the course of human evolution. He sees the main reason for rising above the environment and, thus, the possible development of humans, in the concurrence of four principal mechanisms: insulation, body elimination, neoteny and transference.

Sloterdijk views insulation as the possible limiting factor in selection pressure, which directs the evolution of species to biologically advantageous courses through competing phenotypically effective mutations. In large social groups – and, thus, also in humans – a buffer of environmentally well-adapted individuals can lead to the development of a kind of internal climate. Within the group, and protected by the cooperation of these individuals selected by the environment, less well-adapted individuals were also able to survive. Thus, insulation lowers threat and adaptation pressure levels for individuals living in the middle of the group, a fact that enabled, for example, a longer childhood phase and individual development time leading to an extended ontogenesis that partially allowed non-adaptive development (*ibid.* 176–78).

The second necessary precondition for hominization after Sloterdijk is body elimination. This principle, which Paul Alsberg (1922) noted as the fundamental difference between humans and animals, describes the dissociation from nature through tool use, which eliminates the need for physical adaptation. Sloterdijk considers the picking up of a stone or other hard materials like wood or bone as the primal scene in the bursting of the environmental sphere from an evolutionary perspective and, thus, as the beginning of being human. The use of objects leads to a reduction of physical contact with parts of the environment and enables positive evasion as an alternative to flight and avoidance. In order to cause an environmental change, the actor has to notice an opening in the surrounding environmental sphere, where the intended product can be perceived as the result of own actions. Within this window also appear the first manufactured tools that quasi make humans the co-producers of the opening. The breaking up of the environmental sphere and the accompanying distance from nature intensify during the course of human evolution: Pre-humans become more active and expansive, their range increases, which leads to an interaction between cultural achievements and the channeling of human gene flow (Sloterdijk 2001: 179–87).

Neoteny, the third fundamental factor of hominization after Sloterdijk, builds on the two mechanisms mentioned above. Insulation, as postulated, influences selection. It is not the fittest in the fight against the environment but the most successful in exploiting the advantages of the surroundings that gains a selection advantage within the group. Thus, aesthetically advantageous and cognitively prolific variations can spread, as displayed in human neoteny – an increasing infantilization that already Louis Bolk (1926) recognized as an essential characteristic of the human organism. Birth in increasingly premature condition and the further delay of maturation into adulthood lead to an extended childhood period. The typically human neotenous body with high cognitive potential becomes possible through the technical control over the environment, which creates a kind of incubator. To stabilize and expand this distance from the environment in the long term, control has to be exerted not only over the present but also the future environment, i.e., provisions have to be made (*ibid.* 187–93).

The fourth mechanism in hominization, after Sloterdijk, is transference. The ability to draw on memories and routines enables humans to transfer familiar solutions to new situations. Thus, strange, so far inaccessible and rather deterring conditions can be turned into variations of known ones (*ibid.* 207–9). The range of solvable problems can thus be expanded considerably by the development of just one new solution.

After Sloterdijk, the classical dichotomous classification into thoughts and things, mind and matter fails with regard to the characterization of cultural phenomena, such as tools, symbols, laws, or customs. Rather, he regards these cultural phenomena as a third quality situated between those two poles. The thinking process is incorporated with inventories, where it can be relocated and further processed. Cultural elements are composed by mental and material components and, thus, constitute objectified reflections or information (*ibid.* 217–18). While the animal environment is of a purely material nature and remains separated from the inner perceptions and thoughts of individuals, the created "world" is characterized by the intermingling of thoughts and objects.

In his approach, Sloterdijk describes the evolution of the human mind and thinking as a fundamentally biological process that is complemented by the generation and functioning of (material) culture. It is based on large social groups that, through insulation, provide the opportunity for prolonged childhood periods and not necessarily adaptive developments. Within these circumstances, parts of the environment can be perceived beyond their biological relevance and cultural elements – artifacts – can be manufactured and tested. The transference of known problem solving strategies to so far untouched parts of the environment further extends the human world. Objects that are used as tools in the solution of problems accompany and facilitate this specifically human process of development. Their use leads to a reduced selection pressure on specialized physical attributes as well as to an expansion of the range of operations into situations that so far could only be met by avoidance or flight. While the animal environment rather resembles a backdrop with only few manageable elements, humans increasingly extract components from this background and start to interact with them during the course of human evolution. The environment as backdrop *within* which animals act is, thus, progressively opened into the world *with* which humans interact. Within the separate elements of this human world, material aspects are linked to thoughts. This opening process, which leads from a purely material environment to a world that combines mind with matter, is self-reinforcing through the interaction of its four basic mechanisms.

10 Humans – Thinking – Objects

Everyone recognizes a human being, even though it is difficult to define by means of individual characteristics. Physical attributes are easier to identify but they do not describe the essence of humans. Criteria of the mind, however, are very diverse and its products may vary according to cultures. Whether humans get assigned an absolute exceptional position within or even outside the animal kingdom based on these anatomical, physiological, genetic, and mental attributes or are considered another animal species in a circle of closer and farther relationships lastly remains a matter of definition that cannot be conclusively decided by arguments alone.

Even more difficult than to answer the question “What is a human?” – where at least the diversity of our modern world's population can be brought up as a reference – is to find a response to the question “When do humans first appear?” The sources to consider are limited to rare and fragmented fossil remains that constitute the compendium of a small selection of physical features as well as the material products of the cognitive abilities of early human populations – which in turn are limited to the small percentage that has been materialized, buried, preserved, rediscovered, and recognized as mental products. Taxonomically, the beginnings of being human can be pinned down through physical attributes – any specimen that can be identified as belonging to the species *Homo* is human. However, the term “human” can be stretched to also include our last common ancestors with chimpanzees and bonobos, or even incorporate these primates within the human species (*Homo*; Cela-Conde 1998; Wildman et al. 2003). On the other hand, “true” humans can also be limited to anatomically modern *Homo sapiens sapiens* displaying modern symbolic behavior, which begins to occur more frequently starting around 40,000 years before present. The phylogenetic depth of humans is even more a question of selection and interpretation of data and the significance that is assigned to their interpretation than the distinction of contemporary humans.

Analogous to the various definitions of humans, cognition also is portrayed in different ways. Is thinking a process that is structured functionally along innate lines and then adapted to specific neuronal conditions? Do the anatomical structure of the brain and the organization and functionality of the mind constitute relatively independent units that can be compared to the hardware and software of a computer, as cognitivistic models suggest? Are cerebral functions on the cellular level synonymous with thinking processes, the network structures of which only develop during the course of human life, as connectionistic emergence models postulate? Or is neither of these models sufficient to explain human cognition and does the active role in the selection of perceptions and the construction of information need to be emphasized, as the world construction models assume? From all these different cognition models three developmental dimensions of thinking and different approaches to the origin of the fully developed – adult – human mind emerge. Theories centered on phylogeny place emphasis on the evolution of innate structures, whether they are anatomical or psychological-organizational. Theories centered on individual development focus on ontogenetic development, which, although it is based on genetic foundations, is heavily influenced by the actual environment and individual experiences. The third dimension of development in humans is historical: we increasingly actively alter the surroundings that affect us, thus creating a cultural world that is passed on to future generations as a habitat.

During the course of human evolution, from the last common ancestor of primates and humans to modern *Homo sapiens sapiens*, the physical foundations of cognitive faculties have evolved. The brain has increased in relative size and absolute in relation to body weight, possibly at the expense of the gastro-intestinal system and furthered by a high-energy diet. Besides size, primate brains also exhibit other specific qualitative and quantitative characteristics, such as differentiation of the cortex, neuronal density, neuropsychological mapping of specific capabilities, and varying amounts of different neurotransmitters – all in great individual varieties within the different species. The comparison of mass parameters, such as brain volume, brain weight, or encephalization quotient, are thus not comparisons of otherwise equal units. Moreover, they display no clear correlations, let alone causal relations, to behavioral characteristics and cognitive potential (cf. Holloway 1972: 188–89).

During the course of human evolution, brain growth largely shifted to an extended post-natal period. Certain parts of the brain have relatively increased more than others: The cerebellum is slightly enlarged in comparison to other primate species and the percentage of the cerebral cortex has increased significantly. The prefrontal cortex and the Broca and Wernicke areas are more pronounced, although it can only be said that an increase in size and a shift in proportions occurred. The immediate cognitive consequences and the evolutionary causes of this change can only be speculated upon. The same applies for the evaluation of modifications to individual genes, such as the language-relevant FOXP2 gene, the selection conditions and significance of phenotypical characteristics of which have to remain largely speculative; the same applies to the observed general increase of gene activity in the human brain.

The difficulty of establishing relations to the phylogenetic development of the organization and functionality of the human mind does not only stem from our rather cursory knowledge of physical development processes, their causes, and their effects on cognitive behavior. Apart from the connectionistic models on a cellular level, we are also largely missing models for modern humans that could provide a correlation between contemporary anatomical, physiological, and genetic characteristics and the organization of the mind and mental processes, which go beyond the localization of specific cognitive processes in the brain. The answers to the question whether the organization of human thinking is modular or rather generalized with a possible pivotal point – whether that be language or expanded consciousness – seem to float in strangely empty space, mere developmental-psychological constructs with few links to other areas.

Observations on the localization of brain functions, the failure of specific functions, indicators of the genetic fixation of individual cognitive domains like language, and talents based on cognition but independent from each other suggest a modular structure of the human mind. However, studies on the regeneration of damaged brains and clearly delimited modern functions, such as the ability to speak, write, and do maths, indicate that cognitive areas were not genetically selected as defined modules with specific functions. Possible explanations for this combination of phenomena include, for example, exaptation, which denotes the use of a functional unit for a different purpose than the one that initially let to its selection (Gould and Vrba 1982), and the adaptation of the brain to specific environmental tasks through practice, where the plasticity of the human brain may possibly be furthered by general factors like increased gene activity.

While the different models of the organization of human thinking and its phylogenetic evolution remain largely divergent and hypothetical, language emerges as the common element of typical human thinking. Whether human language capacity has to be viewed as the cause or the result of the evolutionary process, whether the abilities necessary for the complete mastery of language, such as symbolic coding, grammatical structuring, and the perception of others as intentional actors, evolved concurrently, consecutively, or independently up to the ultimately sufficient variation, and what consequences the evolution of these capabilities had on other cognitive areas has to remain open for the time being. However, the fact that language is a key factor in human ontogenesis and the development of culture is undeniable. Language is a cognitive product that, being part of the created lived-in world, acts as an environment. As a means of communication, it also serves as a tool in our supra-individual dealings with our physical and mental surroundings.

Models that focus on the ontogenetic dimension of the development of human cognition emphasize the practical side of interaction with the environment, with members of the same species, or with objects when it comes to the stimulation or development of cognitive operations. Language enables detailed supra-individual communication, so that the experiences of others without own participation and with spatial and temporal distance can be incorporated into thinking and learning processes. At the same time, language is treated as an object and part of the surroundings in itself. Depending on the actual environment, an individual undergoing ontogenesis can and has to confront various elements, with the result that environments created or changed by humans entail vastly divergent experiences.

The formation of the environment lies at the core of the third, historical dimension of cognitive evolution. This dimension is facilitated by phylogenetic changes, although for the time being it is unclear which. Possible initial factors include the perception of others as intentional actors, language, language-related offline-thinking without direct external action context, the progression of executive brain functions, and a fundamental structural change in the neuronal network. Additionally, other, general factors that take effect gradually and with increasing interaction with the environment, such as increased gene activity in the brain, increasing neoteny, or extended brain growth after birth, are conceivable as fundamental driving forces. The historical dimension of cognitive evolution nowadays can be mainly observed in humans. However, rudiments are also found among chimpanzees and orangutans that display group characteristics which can be explained culturally, even if the active transmission of cultural elements is still missing, as is an active, supra-individual confrontation with experiences or problems perceived in the environment.

Products of cultural behavior are artificial material and mental objects. They aid in partial body elimination and artificial body expansion. Their design, manufacture, and use are associated with a dissociation from the environment that can be of a direct physical (e.g., Bolk 1962; Sloterdijk 2001) or reflexive nature (e.g., Bickerton 1995; Donald 2001). The thinking process and its subsequent actions are partially suspended from the immediate external problem context. This indirect approach may make individual elements of mental operations and physical actions seem pointless when viewed separately, but it will still achieve its objective, the solution of problems, when those elements are combined. The perception of intermediate steps as elements that lead to a successful conclusion enables the temporal delay of observed problems, thus leaving new scope for thinking and action and ultimately leading to the solution of so far unsolvable problems (cf. Köhler 1963). The increasing breakup of a direct link between a specific action and the achievement of a goal is also expressed in the transfer of existing complex solution strategies to the solution of new problems (cf. Sloterdijk 2001). The physical and reflexive dissociation from the environment and the transfer strategy are not exclusive but certainly prominent human characteristics that are displayed widely in artifacts and their use.

A common characteristic of products of cultural behavior and artifacts is that they constitute external representations of cognitive processes and as such can again become the objective of thinking processes. Thus, the manufacture of and the interaction with cultural objects expands the basis of meta-reflections, that is, the contemplation of thinking processes, which then – like actions – not only can be carried out impulsively but also controlled actively. Within the context of increasingly past-oriented reflection on already executed operations the future-oriented contemplation of possible actions – mind games and planning – also becomes possible. The perception of others as individuals with their own intentions furthermore enables the conception of actions within an action triangle composed of the subject, another person, and an object. Imitation and teaching are rooted in such triadic constellations, where divided attention is directed towards a material or mental object or event (Tomasello 2002). These forms of cultural learning are shortcuts in individual learning, since no longer every individual has to experience certain situations and devise their own, individual solutions. Rather, the culturally transmitted supra-individual approaches form the basis for further development.

Besides the improved transmission of knowledge within one generation, from older to younger generations and vice versa, as well as the preservation of supra-individual group knowledge over several generations, human cognition is characterized by the ratchet effect. This mechanism not only enables the collection and preservation of behavioral and object innovations but also allows for their expansion and modification. Thus, the solution of a problem can be refined through generations by the accumulation of individual achievements; the development of knowledge turns into a historical process. The individual creation of small openings in the animal environment by means of the purposeful use of individual elements leads to the progressive widening of possible ranges of action and thought by historical accumulation – the creation of a world in Sloterdijk's terms (2001).

Owing to the possibility of three-dimensional development – phylogeny, ontogenesis, and cultural-historic dimension – human cognitive space can expand exponentially (fig. 12). Within this process, cultural-historic development generates a special, self-reinforcing dynamic owed to the ratchet effect. When did this historical development actually take place? Tomasello (2002) assumes it beginnings sometime between six million and 200,000 years before present without elaborating on the structure of this cultural-historic development and its disposable time frame. Slotherdijk (2001) envisions a rather early beginning, which he equates with the first purposeful seizing of an object. Bickerton's theory on the evolution of language (1995), on the other hand, suggests a late start coinciding with the appearance of *Homo sapiens sapiens*. In contrast to the authors mentioned above, Donald (2001) proposes an evolution of cognition, as evidenced by cultural remains, in three stages; he dates its beginnings to around two million years before present and links it to the appearance of the species *Homo* and its assumed imitative capabilities. The first, mimetic stage is replaced around 500,000–400,00 years before present by the mythic stage, which is characterized by the development of language capacity. Around 40,000 years before present, the third, symbolic stage commences, which is defined by the symbolic externalization of thoughts. But what is the actual evidence for these chronological postulates?

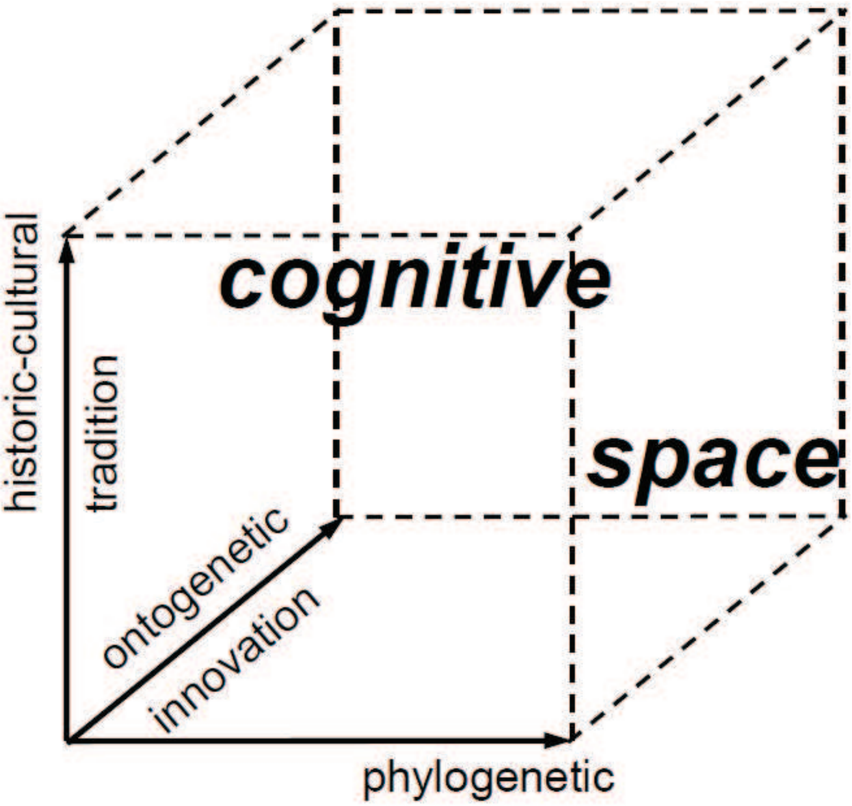


Fig. 12 The three dimensions of human cognitive evolution and the cognitive space they form.

The cultural-historic dimension of human cognitive evolution is accompanied by language and other mental and material artifacts. Numerous correlations between these two groups of cultural products have been observed, but whether there exist causal relations and, if so, how far they go, is still a matter of controversy. Thus, it makes little sense to comb the material remains of early human forms for traces of linguistic expressiveness and cogitation. However, the artifacts themselves can be studied as the autonomous products of cultural-historic cognitive processes without unduly expanding their significance into other domains.

The fact that object behavior plays a pivotal role in the evolution of human cognition is corroborated by various indicators. Conceptual disorders in the sequential organization of movements in the purposeful interaction with objects (ideatoric apraxia) can be localized as specific function areas in the temporo-parietal region of the language-dominant brain hemisphere. Thus, object behavior is a clearly defined cognitive area that is evidently connected with the language-related organization of the brain. During the ontogenesis of modern humans, the practical interaction with objects is regarded as crucial for the gain of knowledge about and the understanding of one's self and the environment. Last, but not least, it is artifacts –

manufactured mental and material objects – that constitute the culturally created world of humans.

Thus, object behavior not only is part of the organization of the mind but also participates in the building of cognitive functions during individual life and active world-making. Owing to this connection with the three spheres of cognition theory and the conclusive link to at least the ontogenetic and historic dimensions of of cognitive evolution, object behavior is ideally suited as the empirical basis of a study on the development of human thinking. How object behavior as a cognitive parameter developed during the course of hominization is best demonstrated by means of the archaeological study of prehistoric remains. The following section introduces approaches to the establishment of an analytical framework that can interpret prehistoric finds and findings in relation to cognition.

III The Search for Cognition in Archaeological Remains

11 How to Extract Thinking from Artifacts

Prehistoric archaeological research uses artifacts – objects and features created by humans – as its primary source. Their interpretation is based on the fundamental assumption that they were produced intentionally: conscious and unconscious mental decisions dictated their manufacture in this specific way and not another. On this basis, prehistoric research pursues typological approaches to the differentiation of groups and the establishment of relative chronologies, and technological approaches that illuminate the history of how the technical knowledge of early populations was applied to the manufacture of objects. Research focusing on functional aspects deals with the probable and actual use of artifacts, while spatial approaches try to discover spatial and stratigraphical structures and relations. Those four methodological approaches, which are closely connected to the material aspects of prehistoric remains, form the core of prehistoric archaeology. Social and cognitive aspects, on which the artifacts can also inform, can typically not be extrapolated from the immediate find context or the description of a complete object or its significant details, but have to be deduced through a more interpretative approach. Despite sometimes vivid discussions during the last decades, these rather peripheral areas of archaeology are only slowly gaining importance.

The introduction to a discussion panel in the *Cambridge Archaeological Journal* (issue 3/2, 1993: 247) subsumes the cognitive approach to archaeology as follows: “Cognitive archaeology…should be that part of archaeology which deals with concepts and perception. In an archaeological context this may be taken to cover the whole spectrum of human behaviour, with especial reference to religion and belief, symbolism and iconography, and the development and expression of human consciousness.” The main topics of cognitive archaeology have surfaced repeatedly ever since archaeology emerged as a field of scientific study, but were rarely the goal of deliberate research. The first systematic studies on the cognitive foundations of archaeological phenomena stem from the 1960s and 70s (e.g., Leroi-Gourhan 1967; Flannery and Marcus 1976; Wynn 1979). “Cognitive archaeology,” a term in use since the 1980s, first emerged as a line of research in the 1990s, mainly in the United Kingdom and the United States. However, its focal points of interest and its methodological approaches to the extraction of cognitive information from artifacts remain inconsistent, owing to its widely differing theoretical foundations.

Searching for Objective Universalities: Processual Archaeology

The 1960s and 70s witnessed the emergence, primarily in the United States, of the theoretically based processual or New Archaeology, whose main, positivist goal is to unearth universally valid facts on human behavior. Its process-oriented and functionalist approach is closely modeled on the scientific method. The aim is to test hypotheses and arrive at objective results by use of neutral and theory-independent empirical data. Refined excavation methods and documentation, quantitative procedures and statistical analysis all help to objectify the data collection process as much as possible. Questions exceptionally suited to this intended generalization deal with the environment, settlements, and subsistence, and are approached through technological studies, use-wear analysis, studies on find distribution and composition, ethnoarchaeological comparisons, and archaeological experiments of the cultural material remains.

New Archaeology considers humans as mammals in their natural environment, whose behavior is determined by their surroundings. The significance of human decisions and, consequently, fundamental cognitive processes has been pushed back to the point where human actions can only be interpreted in a behavioristic manner as automatic reactions to certain external stimuli. Sometimes, human evolution is interpreted as a progressive sequence of socioeconomic phases of organization that – analogous to natural evolution – are necessarily based on each other (Whitley 1998a: 3–6). If cognitive processes as aspects of the development of material remains are accepted at all, as some more moderate proponents of New Archaeology concede, they are either considered as conditions peripheral to the main influential economic or environmental pressures, or as objectively not subsumable. Processual archaeology explicitly incorporates the natural environment and the physical evolution of humans into its interpretations, since they provide the context of human material expressions. Social and cognitive aspects of human object behavior, however, are largely excluded as scientifically not identifiable (Flannery and Marcus 1993).

Cognitive Influences: Structural Approaches and Postprocessual Archaeology

The fundamental objection to the study of the cognitive foundations of human actions as expressed in processual archaeology and the mainly typology-centered European archaeological approaches led to a counter-movement that set out to search for just these connections. As early as the 1960s, André Leroi-Gourhan (1967) applied anthropological structural ideas to the study of Palaeolithic art. Structuralism considers the human mind and its organizational principles as the basis of all artifacts – social organization and myths as well as three-dimensional objects – deeming no artifact category more important than another and positing that all categories can be the subject of research. Mark P. Leone (1982: 742) explains the basic principles of structuralist archaeology as follows: "…first, that all objects in a particular culture are equal with respect to the overall organization and coherence of the total structure of that culture. And second, while the details and particulars of a past culture may be lost, the principles of that organization, or structure, may be suggested through what remains." During the early 1980s, structuralism was taken up by Ian Hodder, among others. At the same time, the first theoretical studies on the newly awakened interest in cognitive aspects of the human past were published (e.g., Leone 1982; 1986). Structuralism and cognitive theory, ideology as expressed in materialist-Marxist approaches, and the conscious approach to history, which later expanded into Critical Archaeology, are all subsumed as topics in the research of the human mind. The direct confrontation of objects as the physical combination of mind and matter was relegated to the background; phylogenetic approaches were not part of the main sphere of interest.

From these approaches, Postprocessual or Interpretative Archaeology emerged during the 1980s and 90s (Shanks and Hodder 1995; Whitley 1998a: 8–13). It defines itself as the critique of processual New Archaeology and vehemently rejects positivism as well as behaviorism. In contrast to Processual Archaeology, which focuses on environmental influences, the postprocessual approach is oriented mainly towards culture and society. Instead of looking for universally valid answers, the individual and its characteristics are centered upon – as a research subject as well as researchers and interpreters of the past. Since already the sampling of data negates their theory-independent existence, postprocessual archaeology does not recognize the scientific method as an objective procedure. And since interpretation in archaeology constitutes a process in itself, there is no such thing as a definitive past. Based on this relativistic point of view, postprocessual archaeology aims for multivocality, as expressed by the varied sociocultural backgrounds of researchers and the different approaches employed – including cognitive interpretation. On the philosophical side, the postprocessual approach is heavily influenced by hermeneutics, the study of interpretation and comprehension theory. As such, one of its central concepts is the significance of cultural expressions, which can only be revealed through the understanding of an artifact's cultural and historical context. Thus, the processual search for general scientific causality is supplanted by the individuality of a cultural phenomenon within its historical context. In contrast to the prevalence of economic, settlement, and environmental questions in Processual Archaeology, Postprocessual emphases are on power relations and symbolic systems in art, religion, and the styling and ornamentation of material goods. The assumed historical individuality of cultural phenomena leads to a general rejection of diachronic comparisons – such as the one that, for example, Leroi-Gourhan (1964; 1967) was trying to find. Although the mental aspects of object behavior are accepted as important cultural elements, the cognitive evolution of humans is not deemed accessible within postprocessual archaeology.

A Melting Pot of Cognitive Approaches: Anglo-American Cognitive Archaeology

“Cognitive Archaeology” itself also formed as a response to New Archaeology, but its rejection of processual approaches is less extreme than within postprocessual archaeology. Like the latter, cognitive archaeology is mainly culture-oriented. It focuses on the cognitive processes that lie behind the material remains and searches the human mind for explanations of behavioral strategies and their material expression in artifacts (Whitley 1998a). This line of research is not based on a unified theory and its development was undefined and unsystematic (Flannery and Marcus 1993: 260). Five contributions to “Viewpoint: What is cognitive archaeology?” published in the *Cambridge Archaeological Journal* (issue 3/2, 1993: 247–70) mirror this diverse understanding of Cognitive Archaeology. Colin Renfrew (1993) defines it as a cognitive-processual approach that runs parallel to postprocessualism. He rejects the validity of a number of postprocessual characteristics, such as relativism, the refusal to generalize, the lack of explicit methodology, and the interpretative approach for cognitive archaeology. In his opinion, the main question in cognitive-processual archaeology is not *what* earlier populations were thinking, since the ancient significance of objects and symbols is difficult to establish, but *how* – how were cultural expressions used in their specific individual context? Additionally, Renfrew detects two key aspects of Cognitive Archaeology. One is concerned with the connection between cognition and tool production as well as language evolution during the course of human evolution, the other is focused on the study of cultural changes among modern humans, such as sedentarization, the formation of cities and states, the emergence of agriculture, writing, metallurgy, and organized religion and ideologies. In contrast to postprocessual archaeology, aspects of economic and settlement history are not rejected but incorporated and elaborated upon through the study of their cognitive foundations.

In his definition of Cognitive Archaeology, Christopher Peebles (1993) stresses the importance of mental capacities and the knowledge that was applied to mastering the respective natural and social environments of prehistoric societies. The study of these aspects is based on the cultural remains that mirror the use of this knowledge. Peebles rejects the narrative and relativistic approach of postprocessual archaeology. By contrast, Cognitive Archaeology should try to link the three worlds inhabited by humans as defined by Karl Popper – 1. all living and non-living things; 2. emotions and self-perception; 3. the respective group-specific knowledge – since they do not exist independently from each other.

Following Ian Hodder (1993), Cognitive Archaeology works with the symbolic and structural content of material remains, incorporates their social and historical context, proceeds hermeneutically in the search for the significance of artifacts within this context, and interprets. However, he rejects cognitive-processual approaches despite strong content-related similarities. His criticism of these approaches focuses on their positivist method, which calls for the testing of hypotheses against objective data, and the lack of attention to hermeneutic problems in the translation between different significance levels. Hodder suggests studying cognition only in connection with the respective society and the social significance of its artifacts. He deems the mere analysis of structures and value systems as insufficient, since it can only expose existing variability without contributing to the understanding of its underlying causes. But the knowledge that an individual can access is always also characterized by a social framework: the rules, limits, and proclivities of a society. Hodder detects three forms of socially influenced cognition in archaeology: 1. linguistic cognition, which applies to all sign systems that are organized by rules and thus further communication, like language, writing, and material symbols; 2. practical cognition, which subsumes movements, technological knowledge, and emotions; and 3. the thinking of archaeologists themselves.

Barbara Bender (1993) does not recognize Cognitive Archaeology as an independent line of research but sees it merely as a form of cultural materialism. While she concedes the necessity of increased attention by archaeologists to their own role and the perception of their own subjectivity, as postprocessual cognitive archaeology demands, she views the resulting liberal multivocality as subject to possible arbitrariness, where the individual autonomy it expresses only reflects the political system of the western world. Thus, Bender focuses mainly on the question of power – in prehistoric societies as well as in modern academia. Cognitive Archaeology helps to identify power structures in prehistoric societies; physical structures like hillforts, enclosures, and ditch systems can express power by the way they include or exclude, signify permission or prohibition, limit, or exert pressure.

As extreme representatives of a processual cognitive approach, Kent Flannery and Joyce Marcus (1993) view Cognitive Archaeology as a complement to basic subsistence and settlement archaeology. Its key points of research are, in their opinion, all those aspects that stem from the human mind, such as cosmology, religion, ideology – expressed in concepts, philosophy, ethics, and values –, iconography, and all other forms of intellectual and symbolic behavior. Flannery and Marcus stress that these topics are not peripheral phenomena, but often form the basis of an understanding of subsistence and settlement behavior and changes therein.

They reject the notion of "Cognitive Archaeology" as a separate line of research and argue for a generally more holistic approach, since studying the cognitive foundations of material phenomena, where applicable, is part of every archaeologist's task. Topics like cosmology, religion, and ideology, however, can only be studied under methodologically rigorous conditions and in cases where sufficient background information, such as historical documents from within or outside the studied group, is available.

Taken together, the five positions expressed in "Viewpoint: What is cognitive archaeology?" published in the *Cambridge Archaeological Journal* (issue 3/2, 1993: 247–70) do not offer a clear definition of the theoretical and methodological lines along which Cognitive Archaeology is structured – quite contrary to the situation in Processual and Postprocessual Archaeology. Rather, it resembles a patchwork of different directions taken in the assessment of its key topic: the mental foundations of archaeological remains. On the one hand, Cognitive Archaeology is considered an extension of Processual Archaeology, when dealing with the causative explanation of behavior in economy and settlement organization, although environmental and behavioral explanations are rejected. On the other hand, there is a distinct overlap of cognitive and postprocessual interests and lines of research on such topics as cosmology, religion, ideology, value systems, iconography, and symbolic behavior. Consequently, postprocessual archaeologists often assume that Cognitive Archaeology can be equated with Postprocessual Archaeology if its processual elements are rejected. A third line of research is concerned with the cognitive evolution of humans; it expands on the primarily scientific research in hominid evolution and generally follows processual procedures.

From Theory to Practice in Cognitive Archaeology

When considering recent publications with cognitive archaeological content (e.g., Gibson and Ingold 1993; Lock et al. 1994; Renfrew and Zubrow 1994; Mellars and Gibson 1996; Mithen 1996; Renfrew and Scarre 1998), rather than the associated theoretical discussion, it becomes increasingly clear that Cognitive Archaeology incorporates processual as well as postprocessual elements and does not view itself as an extension of an archaeology primarily concerned with settlement and subsistence questions. Rather, it constitutes its own line of research, the key interest of which lies in studying the development of human thinking – an original approach not covered by other lines of research. In the chapter "What did they think? Cognitive archaeology, art, and religion" of their popular textbook, *Archaeology: Theories, Methods and Practice,* Colin Renfrew and Paul Bahn (2000: 385) call for the development of explicit procedures in the study of concepts and ways of thinking within early societies. When dealing with the evolution of human thinking, models derived from developmental psychology are often used as a basis, and archaeological remains are sifted for their equivalents. Examples of this practice include Jean Piaget's theories on logical and spatial intelligence (see Piaget 1985), used in the works of Thomas Wynn (1979; 1981; 1985); Howard Gardner's model of multiple intelligences (1991) in the studies of Kate Robson Brown on early Palaeolithic artifacts (1993); and the studies by John Tooby and Leda Cosmides (1989; 1992) and Annette Karniloff-Smith (1992) on the transition from specific intelligences for certain areas of knowledge to a generalized intelligence, which influenced the writings of Steven Mithen (1994; 1996).

In an epistemological assessment of studies on Palaeolithic cognition, Isabelle Saillot et al. (2002) detect three core themes:

1. The search for indicators of modern cognitive capacities, where the evaluation of the same indicators varies according to the initial view taken (“capability x is recent”; “capability x is old”).
2. The reconstruction of the development of cognitive capacities, which is either approached as a theoretical question, as a matter of tool development, or is summarily rejected.
3. The development of models of cognitive capacities during the Palaeolithic. While some researchers deem this development basically impossible, others insist on new, specific approaches, since they consider models developed for modern humans as non-transferable to animals or pre-modern humans. A third group considers the deduction of Palaeolithic cognition models from modern ones as feasible.

After Saillot, it is not possible to compare the different studies on Palaeolithic cognition directly, since the terminology they employ is derived in part from different fundamental concepts that are often not clearly defined. For example, the term “planning,” as used in the context of tool manufacture, describes a mental concept of sequential actions and thus differs from “planning” in terms of subsistence, or the spatial planning of settlements or temple compounds. The approaches also differ in their fundamental theoretical views of the development of the human mind – genetic, cognitivistic, looking for increasing complexity, focused on primatology or zoology in general – and their assumption of what constitutes typical human behavior (e.g., language, symbolism, complex behavior, or no special characteristics). The choice of the method of research and the archaeological material considered as relevant is completely dependent on the choice of approach (*ibid.,* 9).

The main chronological focus of publications dealing with the development of human thinking and often covering the cognitive-archaeological angle only by implication is centered upon the transition from the Middle to the Late Palaeolithic; thematically, the focus is on the first appearance of modern cognitive capabilities. All those publications suffer from a lack of explicit methodology, as criticized by the processualists, combined with a lack of attempts to arrive at more profound interpretations, as the postprocessualists criticize. Instead, although approaching the topic from different angles, these studies all enumerate more or less the same indicators for or against a cognitive or symbolic and/or linguistic revolution around 50,000–40,000 years before present (Chase and Dibble 1987; Trinkaus 1989; Binford 1989; Whallon 1989; Mellars and Stringer 1989; Hayden 1993; Klein 1995; Noble and Davidson 1996; Mellars 1991; 1996; Otte 2001; Coolidge ans Wynn 2001; Klein and Edgar 2002; Mellars 2005). With a few exceptions, such as Mithen (1994; 1996) or Coolidge and Wynn (2001), no cognitive explanation of the postulated symbolic revolution is provided, apart from the merely conjectural argument of a sudden and not further specified genetic mutation, which for example Klein and Edgar (2002) put forward. Alternate approaches to the development and early use of material symbolic systems in Palaeolithic times are missing. Colin Renfrew's fundamental critique (1996), namely, that the presented indicators of changes accompanied by a cognitive revolution are sparse and often include circular arguments, still applies. His ensuing demand for the development of more effective methods for the study of cognitive processes should be taken as an incentive to further methodological and theoretical developments within Cognitive Archaeology.

The French Way: The Technological Concept of *chaînes opératoires* and the *schéma conceptuel*

Parallel to the Anglo-American discussions of Cognitive Archaeology between processualism and postprocessualism, another cognitive-archaeological line of research, this one based on ethnological approaches (Lemonnier 1983; Karlin et al. 1991), emerged in France during the 1980s (Pelegrin 1985; 1990; 1991; Pelegrin et al. 1988; Nelson 1991; Sellet 1993). Based on technological processes that are interpreted as action chains – *chaînes opératoires* – it attempts to approach the thinking processes these chains are based upon – the *schéma conceptuel;* its main employ is in the study of Palaeolithic groups (e.g., Geneste 1985; Ploux 1989; Boëda et al. 1990; Saillot 2002; Boëda 2005). Ideally, all technical and decision processes that occur during the “lifetime” of an artifact – from the selection of the raw material through the manufacture of its basic form, its modification by shaping or remodeling, to its final discarding – can be recorded as a *chaînes opératoires,* i.e., organized chains of individual actions (fig. 13). Within archaeology, stone tools constitute an ideal data set, since they occur frequently and are mostly resistant to erosion, so that even the debitage from their manufacturing process can be recorded, and reconstitution allows an almost unbroken reconstruction of subsequent actions.

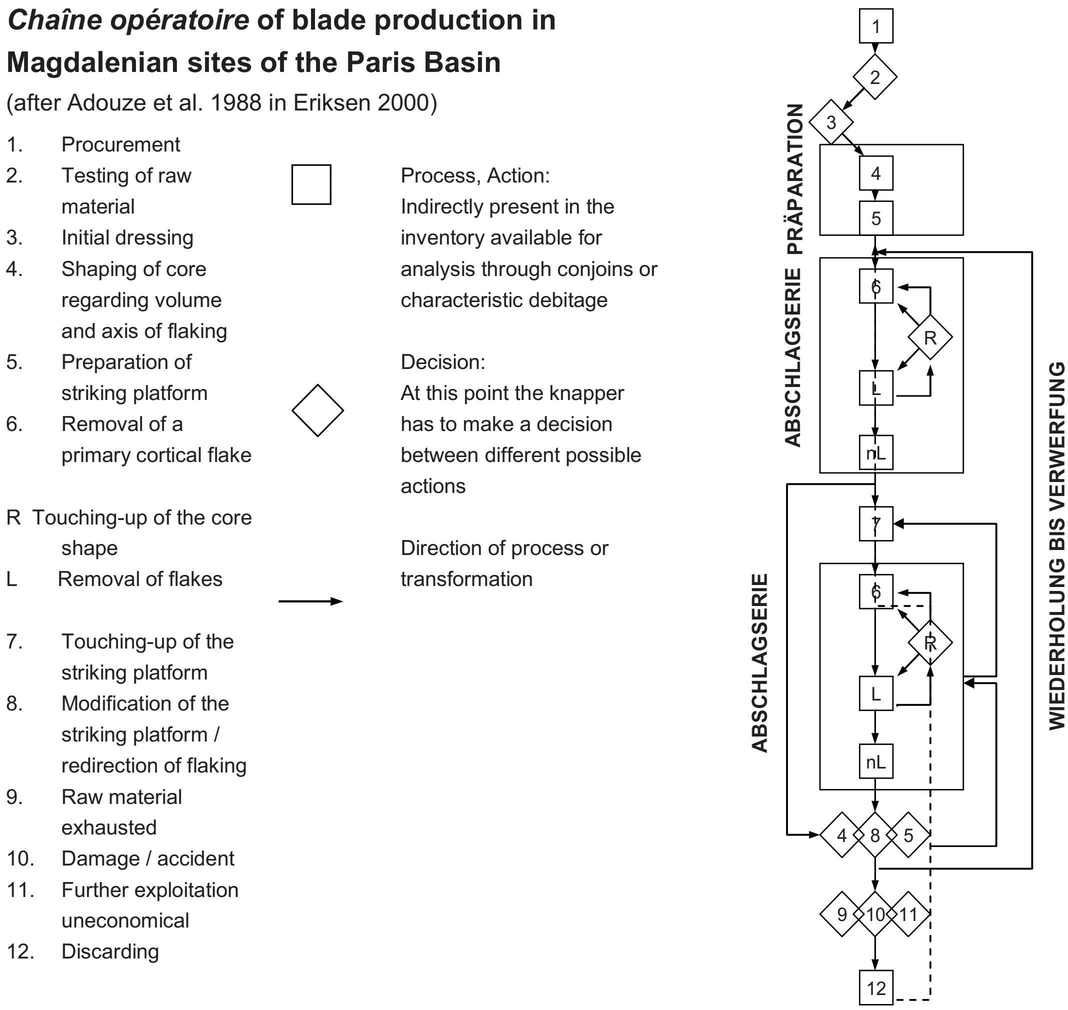


Fig. 13 Example of a *chaîne opératoire* (after Adouze et al. 1988, in Eriksen 2000: fig. 6).

Karlin and Julien (1994), van der Leuw (1994), and Schlanger (1994) all incorporate the theoretical background of the *chaînes opératoires* concept with their derived conclusions and thus place the detailed recording of technological and associated concepts within the realm of Cognitive Archaeology. Thus, after Lemonnier (1990), the processes and techniques within a given group constitute social products: they are the materialization of socially acquired concepts. Accordingly, Boëda (1990) views the Levallois flaking technique not merely as a certain method to produce flakes but as the expression of a distinct concept (*schéma conceptuel*) of cores possessing a striking platform for the desired flakes. It follows that the Late Palaeolithic is not characterized by the final blade product, but by a different core concept that allows for three-dimensional instead of two-dimensional reduction.

Pelegrin (1990; 1991) distinguishes between *connaissances,* the conceptual knowledge or mental representation of ideal forms and materials within a group, and *savoir-faire,* the technical knowledge about the mental and physical execution of a process. *Connaissances* and *savoir-faire* – concepts and methods – together form a techno-psychological axis, while a techno-sociological axis including cultural, spatial, and economical interdependencies influences the application of this knowledge. Besides conceptual and technological knowledge, Sylvie Ploux (1989; Pelegrin 1990) additionally acknowledges the intention to act and the mastering of the execution as further independent factors in tool production. In her analysis of the Magdalenian site at Pincevent, she recognizes not only different levels of competence – beginners, ordinary knappers, and specialists – but also two different percussion techniques: tools intended for future, i.e., delayed, use were standardized and only produced by specialists, while tools intended for immediate use were also manufactured by less experienced individuals. A similar teaching/learning situation is found in the silex inventory of the Magdalenian station Etiolles, according to M. Olive (1988) and Nicole Pigeot (1990).

This rather technologically oriented French line of research has so far gained little access into Anglo-American dominated Cognitive Archaeology, even though it constitutes one of the stipulated methods in the research of prehistoric concepts. Similarly, the theoretical approach to Cognitive Archaeology has met with only minimal notice in France and Central Europe. One result of this non-ideological approach to specifically human behavior and the method of process description is that the concept of *chaînes opératoires* could be transferred to animal tool production (Beyris and Joulian 1990; Joulian 1996); thus, human cognition derived from artifacts can be considered on a directly comparable level.

The different theoretical foundations and methodological approaches to the extraction of cognitive components in archaeological inventories show a very heterogeneous picture. Their lowest common denominator is the certainty that artifacts constitute the realization of ideas in objects. The answers to whether these cognitive elements are, in fact, accessible and how this access can be realized, are as diverse as those to the questions about the physical and psychical basis of human cognition and its nature in the approaches of the cognitive sciences, philosophy, psychology, neuroanatomy, and genetics.

The following chapter presents archaeological models of the development of human cognition. These are often quite closely related to models from other fields of research and attempt to reconstruct their inner concepts within the archaeological source material. The discussion of the methods used to extract cognitive aspects is particularly interesting.

12 Models for the Evolution of Human Thinking Supported by Archaeology

Prehistoric research has in various ways commented on the interplay of mind and matter that finds its ultimate expression in artifacts. The examples presented in the following do – as a rule – not build upon each other and thus present mainly independent lines of research. They approach the question of the evolution of human thinking and its expression within archaeological contexts from widely varying angles. In general, the prehistoric approaches mirror the varied approaches by other disciplines concerned with cognition. Thus, there are cognitivistic as well as connectionistic models; they are all more or less phylogenetically oriented, with mostly minor ontogenetic influences.

Surprisingly, archaeological discussion for the most part excludes the active participation of prehistoric groups in the evolution of cognition – postulated as an essential part by constructionist or world creation models within the cognitive sciences (see Varela 1990: 90) – from its considerations. The third, cultural-historical, dimension of development (after phylogenetic and ontogenetic history) almost exclusively comes into play only after ca. 40,000 before present, with *Homo sapiens sapiens* as the carrier of culture whose modern human thinking expresses itself mainly in his expansion to previously uninhabited territories and the use of figurative art. A cultural-historical development during the preceding periods is generally rejected, owing mainly to the slow pace of regional diversification and technological progress during that time. The dominant anthropological-scientific approach employed in the study of early prehistory has resulted in the search for primarily phylogenetic explanations and the exclusion of possible answers found within this field of study itself, which actually contains a wealth of cultural-historical context relevant to the evolution of human cognition.

The Palaeontology of Human Thinking

In his fundamental work on the evolution of human cognition, *La geste et la parole* (1964/65), famous French prehistorian André Leroi-Gourhan (1984) reaches back to his palaeontological roots to explain the evolution of technology, language, art, and consciousness as the physical liberation of the spirit. In his opinion, it is the upright walk that constitutes the initial characteristic change that precedes and triggers all other physical and mental developments leading to modern humans (fig. 14).

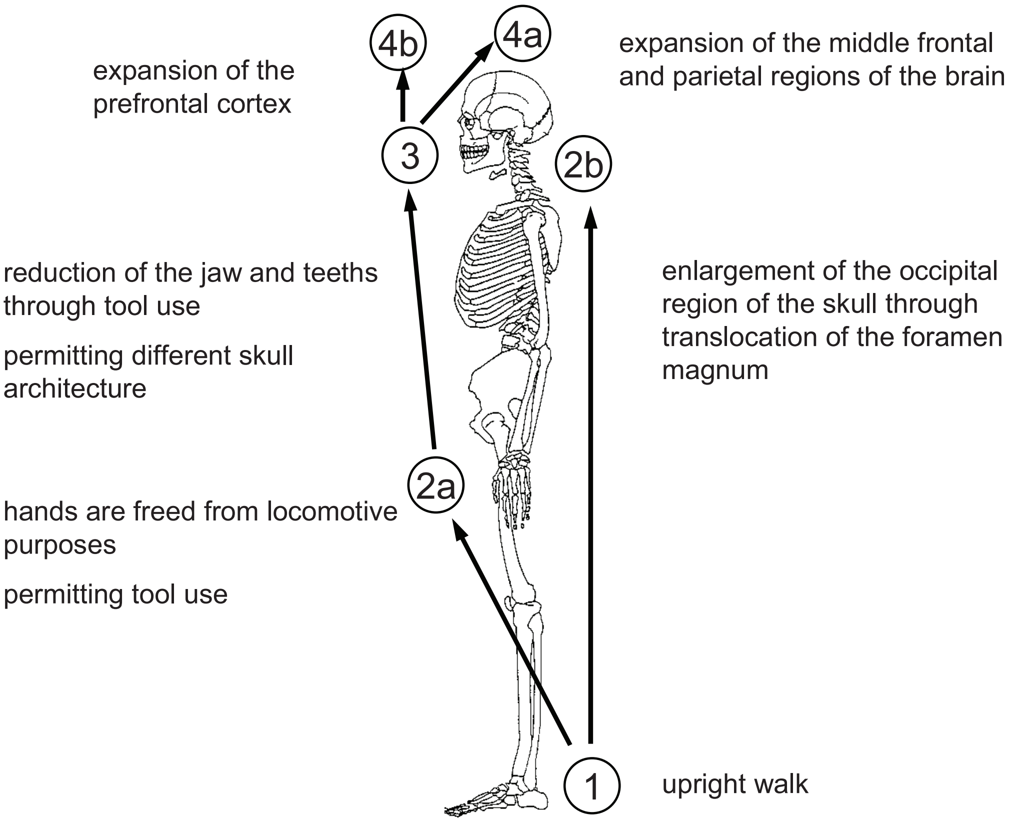


Fig. 14 Leroi-Gourhan's model of cognitive evolution (1984): Steps in physical evolution leading to anatomically modern humans. Human cognitive evolution causally follows these physical changes.

Thus, the translocation of the foramen magnum underneath the skull freed the occipital area and facilitated the enlargement of the brain, just as the upright walk freed the hands for technological purposes. The reduction of the jaw and the masticatory muscles, which resulted from technological solutions, led in the course of time to a different skull architecture and, consequently, to the “unlocking of the forehead” (Leroi-Gourhan 1984: 170), which in turn resulted in the characteristic prefrontal cortex that is typical for modern humans.

According to Leroi-Gourhan, the freeing of the hands caused by upright locomotion was the initial cause for the development of technology and object manufacture, as opposed to the merely *ad hoc* use of objects among animals. While he certainly views the developing technological intelligence as a zoological phenomenon (*ibid.*: 130), he also stresses that humans are not just slowly improving apes, but have to be regarded as completely different beings once tool use can be ascertained. The free and not completely determined element that is expressed in the tools, and which probably encompassed actions as well as vocal expressions, characterizes a new organization of thinking that should be viewed not as biological evolution, but rather as a step away from zoological bounds (*ibid.*: 152). Among the primary characteristics of humans, Leroi-Gourhan counts the upright walk, the short face, the hands freed from locomotive purposes, and the use of movable tools; he classifies the increase in brain volume as secondary (*ibid.*: 36). However, humans in the strict sense of the word are characterized by symbolic thinking (*ibid.*: 237) and the "domestication of time and space" (*ibid.*: 387).

The discovery, in the late 1950s and the early 1960s, of a simple stone tool culture and remains of *Zinjanthropus* (today: *Australopithecus boisei*) within the same sediment layers of Olduvai Gorge, northern Tanzania, by Mary and Louis Leakey led Leroi-Gourhan to search for the pre-human–human transition already among the australopithecines. Since with upright locomotion the use of teeth and mouth as tools shifted to the now free hands and the manual use of external tools, the mouth was now mostly free for language (*ibid.*: 55). Leroi-Gorhan also detects the interconnection of "hand and word" in the cortex areas for verbal and gestural association, which he sees as already clearly pronounced in the australopithecines (*ibid.*: 118). Parallel to technological differentiation and increasing complexity he assumes the development of language capabilities – from single and partially deliberate vocalizations among *Zinjanthropus,* through more complex variations among the manufacturers of bifaces, to the possible transmission of symbolic content starting with the last Neanderthals (*ibid.*: 151). While the technological intelligence of human ancestors up to *Homo erectus* only developed slowly, the growth and diversification of the middle frontal and parietal areas of the brain that Leroi-Gourhan observed led to a highly developed, if still mainly technological, intelligence in the Neanderthals. But it was only the development of the prefrontal cortex, which controls emotions, prevision, consciousness, reasoning, and thus the reflection of behavior, that cleared the way for increasingly conscious, non-functional actions, symbolizing actions, and creative consciousness.

It is this developing potential of the prefrontal cortex that shattered the bonds of biological evolution, according to Leroi-Gourhan. While our biological species up to the Neanderthals functioned in their role of transmitters of memory mainly through inherited instincts and the development of action chains dependent on single individuals, these deliberate innovations increasingly made use of the ethnic group as social memory carrier; language acted as the transmitter of memories and experiences, and the development of action chains became a supra-individual process. Leroi-Gourhan finds testimonies of cognition that exceed material-technological thinking already at the end of the Mousterian period and during the Chatelperronian, as expressed in burials, collections of aesthetically pleasing objects such as color pigments and fossils (*ibid.*: 144–45), and the expression of thoughts and ideas in graphic symbols or rhythmic notches (*ibid.*: 237). The disassociation of thinking processes from immediate necessity then led to an explosion of artifact variety and symbols during the Late Palaeolithic. Since the choice between alternative action chains is only possible if consciousness and language are involved, the freedom of alternative behavior only exists on a symbolic level, but not on the level of direct actions. In contrast to animals, humans are capable of projecting their actions by freeing them from material dependencies and changing them to chains of symbols.

Leroi-Gourhan's model of cognitive evolution is based on physical changes that allowed a progressive “emancipation” of the anatomy and its functions from locomotive and subsistence-related tasks. This disassociation is paralleled by an increasing externalization of acting capacities – from an originally direct use of hands, mouth, or teeth as as tools; through the direct motor use of the hands when using objects as tools; the indirect motor use when manual machines are employed, such as the atlatl beginning with the end of the Late Palaeolithic; to finally the use of the hands as mere activators of motor processes, such as for example water-driven mills in historical times. The very recent employ of programmed processes in automated machines constitutes the externalization of wide areas of action and influence: the tools, their manipulation, the gears, the process memory, and the individual treatment of the blanks according to their mechanical characteristics (*ibid.*: 302). Besides the external relocation of acting capacities, modern humans also exhibit external relocation of memory into writing, time into artificial rhythms, and social symbols into artistic expressions, such as jewelry.

Leroi-Gourhan's focus is on physical evolution as the basis of mental development that is reflected in artifacts. He sees artifacts merely as secondary sources that can be classified according to functional and symbolic content or use. In the development of functional tools he sees an increasing technological complexity over time, which he does not differentiate further. It is only with the end of the Middle and the beginning of the Late Palaeolithic that he detects deliberate actions and the development of symbolizing capabilities, which are displayed by, for example, aesthetical expressions that go beyond merely technological intelligence. Several finds of an earlier date, which Leroi-Gourhan may have interpreted as evidence of rhythmic fixation, such as the incisions from Bilzingsleben or the sophisticated tool behavior among chimpanzees and orangutans, where still unknown when he formulated this model.

Piaget's Stage Model of the Evolution of Intelligence in the Archaeological Context

While André Leroi-Gourhan's approach to the reconstruction of the development of human thinking is centered around physical evolution, Thomas Wynn (1979; 1981; 1985) attempts to transfer Jean Piaget's stage model of the ontogenetic development of intelligence (see Chapter 8) to phylogeny and to apply it to Palaeolithic artifacts. In this process, he defines intelligence as the capability to organize one's own actions in a complex manner. Its foundations are genetically determined structures that evolve into increasingly complex forms of organization during the individual process of maturation. Wynn roughly summarizes Piaget's stage model into three stages. The first, infant stage of sensorimotor intelligence includes the simple action intelligence without internal representation of the action. In this phase an action cannot be anticipated mentally. The second stage of preoperational intelligence is characterized by the appearance of internal mental images of actions; the capability to visualize actions is the precondition for the projection of future actions and the reflection on past ones. During this stage, however, thinking is restricted to a sequence of individual actions that have to be processed consecutively. Thus, the results of actions can be anticipated, but the contemplation of changes has to focus on one variable at a time; the results of a combination of different variable factors cannot be anticipated. Consequently, the planning of actions during this stage has to focus on one variable and will employ the trial and error method (Wynn 1981: 531).

It is only the third stage of concrete operational intelligence that allows for the processing and coordination of different variables at the same time. The mental simulation of action sequences leading up to a result or, inversely, the extrapolation of necessary steps to be taken from a desired imagined result allows for more complex planning (Wynn 1985: 34). The mental reversibility of actions and the possibility to return to the starting point when a mentally chosen approach turns out to be unprofitable makes it possible to correct mistakes before they are physically carried out (Wynn 1979: 373–74). In contrast to Piaget, who combines the preoperational and concrete operational phases into one stage that extends up to the 11th–13th year of a child's life, and who only then assumes a third stage of formal operational intelligence (Piaget 1970), Wynn ends his second stage with preoperational intelligence; this is followed by the concrete operational and formal operational subphases, which combine to form the stage of operational intelligence. While, initially, concrete sequences of action can be organized only in physical units, such as objects or other persons, a second step allows for the mental simulation of purely imagined operations, i.e., the contemplation and organization of theoretical assumptions and hypothetical units.

Since the sequence of stages in Piaget's ontogenetic model is necessarily logically determined, because each stage is a further development of the preceding one, the same sequence applies to Wynn's phylogenetic model (Wynn 1981: 532), and for the same reasons. In his studies of the phylogenetic evolution of human cognition, Thomas Wynn transfers essential deductions from Piaget's stage model and ensuing concepts of spatial thinking (Piaget and Inhelder 1967 in Wynn 1979) to the archaeological record. Modern primates exhibit mental concepts of desired results, as well as the computations of means to achieve them. In this manner, natural objects such as twigs or vines are deliberately modified to act as termite fishing devices; however, primates can only use the trial and error method, which is characteristic of preoperational intelligence (Wynn 1981). Even in early Old Palaeolithic times, with its Oldowan technology, Wynn does not see any indicators pointing towards more than preoperational thinking. The problem to be solved existed as a vague visualization; the intention allowed a projection of actions into the future. However, only one variable at a time could be contemplated, so that a stone tool had to be flaked in single, incoherent steps until it finally served its purpose – the solution of the problem. The emergence of different classes of artifacts, where specific forms served as standard tool solutions for specific purposes, cannot be detected during the Oldowan.

While Oldowan and Developed Oldowan artifacts can be manufactured without operational intelligence, according to Wynn, this kind of intelligence is a prerequisite for the manufacture of Acheulean handaxes. Wynn detects four modes of operational spatial thinking in the production of these stone tools (Wynn 1979). He regards bifacial tools with only minimal reworking, but which nevertheless exhibit the characteristic shape of the handaxe, as evidence for the perception of an object as a whole and the retouching flakes as parts thereof. In order to minimize necessary modifications, the reversibility of the mental sequence of actions is prerequisite. The intentionally straight retouching, especially of later handaxes, can only be achieved if each percussion is considered in relation to others, according to Wynn. And with the help of mental reversibility, these spatial relationships of individual elements are not only perceivable when they already exist, but can also be caused deliberately.

In the symmetry exhibited by the handaxes, Wynn sees the manifestation of two characteristics of spatial-operational thinking. On the one hand, relationships between individual elements are perceived as potentially transferrable to other spatial or temporal contexts. The symmetrical cross-sections of handaxes cannot be achieved by flaking sequences based on the trial and error method; rather, invisible view points have to be constructed based on available visible views. However, Marie-Louise Inizan et al. (1992: 42) point out that the symmetrical cross-sections do not necessarily constitute a deliberate choice but may have been the inevitable result of the bifacial technology in handaxe production. On the other hand, Wynn (1979) perceives in the frontal view of the bilateral symmetry of the edges, in both its parallel (congruent) and mirrored (inverted) variants, the repetition or reversal of an equivalent relationship of elements, where all dimensions of this relationship have to be identical. Thus, in order to create symmetry in the frontal view, measurements taken with the help of some kind of reference are necessary. Especially for the early handaxes, however, Wynn leaves open the question of whether the symmetry of the handaxes was indeed an intended result or merely exists in the eyes of modern beholders.

Due to his classification of the development of intelligence, which differs from the stages assumed by Piaget, Wynn (*ibid.*) sees all spatial-cognitive criteria of modern, adult, operational thinking met by 300,000 before present at the latest. While Piaget views the time between 12 and 16 years of age as a major marker in the development of intelligence – the progression from the concrete operational to the formal operational stage – Wynn defines the formal operational stage as a simple extension of the concrete operational stage, which cannot be evidenced in the archaeological record and is negligible from a technological perspective. He sees the first indicators of operational intelligence, as expressed by the reversibility of mental action sequences, already in the Upper Bed II of Olduvai, about 1.1 million years before present. Judging from the technology, he detects no increased intelligence during the Late Palaeolithic, since the spatial concepts behind blade technology are no more complex than those behind the bifacial or Levallois technologies. Thus, Wynn merely acknowledges a cultural development after the Acheulean but rejects the assumption of a further increase of genetically determined cognitive potential.

Wynn sees further evidence for his results, which were obtained by transferring Piaget's stage model to the archaeological context, in divided standards exhibited by the handaxes. In contrast to the Oldowan artifacts, which do not show specific shapes, bifacial tools rely on certain conventions. Social knowledge influences the shape of artifacts starting with the Acheulean, and their uniformity is based on the perception of an adequate shape by other members of the group. The manufacture of handaxes can thus not be learned through the simple repetition of other group members' actions, but requires the perception of others' purposes as purpose (Wynn 1993). Such conventions or standards are not tied to immediate problems but exist independently from them: tool types are standard solutions, the concept of which does not have to be re-invented each time. Thus, Wynn implicitly identifies Tomasello's key innovations of modern human behavior – the "perception of others as intentional actors" and the ensuing "cultural ratchet effect" – already in Acheulean tools (see Chapter 9; Tomasello 2002).

The problem of deducing generally increased intelligence from certain characteristics of stone tools is elucidated by the studies conducted by Christophe and Hedwige Boesch (1984) on the stone hammer transport among chimpanzees in Taï National Park, Ivory Coast. This long-term study showed that chimpanzees not only possess a measure to judge distances between different stone hammers and certain nut-bearing trees, but that they also keep this measure independently of their own position and without direct sensory input. They are also able to compare an average of five different spatially positioned distances with a mental map and to choose from them the shortest distance to a targeted tree; the weight of the stones is also taken into account, if on a somewhat secondary level. Additionally, this mental map of stone hammers and nut-bearing trees can be adapted according to hammers already transported to other locations, and the reference point (a different tree) can be changed as well. Boesch and Boesch (1984: 168–69) thus prove the existence of Euclidian space with measurements and distances among chimpanzees, the same space that is assumed to exist among human children of the concrete operational stage, after about nine years of age, according to Piaget. Wynn's studies (1979; 1981) of Old Palaeolithic chopping tools and handaxes consequently only apply to the manifestations of Piaget's stages of intelligence in stone tools and cannot be expanded to apply to the general thinking of early human forms. Wynn himself cautions that intelligence displayed in material execution and the archaeological context has to be regarded as minimal competence: “The prehistoric actor may have used more sophisticated abilities in realms of behavior that are archaeologically invisible” (Wynn 1985: 33).

Depth of Planning, Projection, and Organized Action

In contrast to Wynn, who attempts to unravel the development of cognitive potential from the conceptual characteristics of prominent artifact types and their manufacture, Lewis Binford's approach (1989) ties human cognitive evolution to our capability to plan ahead, which he sets out to detect in both the macro- and microstructures of archaeological remains. Motivated by passages from A. L. Kroeber's textbook (1923), Binford revisits Kroeber's idea of modern humans that differ from Neandertals by “patience and projection.” After Binford, modern human populations are characterized by several traits pertaining to these attributes:

- He uses the term *Depth of Planning* to describe the period of time between the anticipation of actions and their actual, thus facilitated execution, the amount of work expended in the anticipation, and the amount of thus facilitated actions. The higher the depth of planning, the more steps in tool production can be observed, and the higher is the number of tools that are used in the manufacture of other tools. These often simple or coarse production tools must not be confounded with the tools of earlier periods, since they are based on a different depth of planning.
- The *Tactical Depth* is defined as the capability to find different possible solutions to a problem based on stored knowledge about mechanical principles, environmental characteristics, and other opportunities.

- *Curation,* finally, is used by Binford to describe the degree of maintenance evident in a tool assemblage. Curation can be assessed through the intensity of use of different raw materials, their transport over long distances, and the ease of replacement of individual elements in composite tools, among others.

According to Binford, modern hunter-gatherers display in their behavior a great variety of depth of planning, tactical depth, and curation that is primarily dependent upon the availability of resources and thus the ecology of the populations in question (Binford 1989: 19–22).

For the Early Palaeolithic, Binford only detects a few indicators of minimal planning. The sites are not structured into different areas, which indicates that the spatial use of those sites was not planned. While both during the Oldowan and the Acheulean raw materials were transported to the sites, Binford views this transport as episodic and not in need of consistent planning. The few observed maintenance procedures evident from tools transported to other sites were, according to his observations, carried out in all sites with the same probability; a differentiation of activities between base and hunting camps, as his model for Late Palaeolithic hunter-gatherer groups suggests, did not take place. Although during the Acheulean the extent of the territory populated by *Homo* outside of Africa increased considerably, Binford detects no specialized tool inventories adapted to different ecosystems at this time. From this, he deduces minimal variation in social organization, the lack of cultural inheritance mechanisms, and thus the lack of cultural systems. He concludes that whereas adaptive processes during the Early Palaeolithic were facilitated technologically, their base mechanism was biological, similar to that of chimpanzees. He rejects the occurrence of hunting activities, which would indicate planned behavior, even for Late Acheulean times (*ibid.*: 25–31).

While Binford detects increasing spatial-temporal inventory units during the Middle Palaeolithic, he does not see them to originate within populations conscious of their own culture. Although there is a clear difference between the transport and use of raw materials of varying qualities (curation), the depth of planning has to be considered low, according to Binford, since the tools are not manufactured or maintained centrally, but still in the place where they are needed. The turnover of artifacts is generally high, but their maintenance is low. Binford does not detect a spatial structuring in Middle Palaeolithic sites; they are merely the product of episodic presence. Tools used in tool manufacture would point to successive planning steps in technology, but Binford doubts their existence during the Middle Palaeolithic. Overall, he views Middle Palaeolithic humans as not adapted to differentiated environmental conditions, neither in group size nor in technology, with limited mobility and flexibility. Parallel to the Early Palaeolithic, he does not see any indicators for hunting, just for the scavenging of carrion (*ibid.*: 31–35).

It is only with the Late Palaeolithic, that Binford detects the true technological and thus cultural adaptation to the environment, which is based on new means of organization through language. The increase in variation is seen in the size, the permanence, and the spatial differentiation within and between the sites, new structural and find categories, such as burials, art, and personal ornaments, as well as new raw materials like bone, antler, and soft stone. Planned hunting and the use of tools to manufacture other tools also only occur with the late Palaeolithic, according to Binford. For him, the rapid change towards a flexible adaptation to extremely varying environmental conditions is the main difference to all previous, slow changes and can only be explained by the cultural evolution taking place about 40,000 years before present (*ibid.*: 36–37).

The fundamental differences between the Middle and Late Palaeolithic regarding planning and technological organization, postulated earlier by Binford, are critically discussed by Roebroeks, Kolen, and Rensink (1988), especially where they pertain to the use of stone tools and their raw materials. During the Middle Palaeolithic in Central Europe, raw materials in different stages of reduction up to the finished products were transported to and from various sites (e.g., Maastricht-Belvédère C and G, Rheindahlen Westwand B1, Lehringen, Sclayn, Schweinskopf); their distance to the original source of raw material can amount up to 100 km. The spectrum of transported, used, modified, and sometimes further transported goods included prepared cores, flakes from different specialized flaking sites, and hand axes. According to Roebroek et al., the transport, planned maintenance of the assemblage, and extension of duration of use through reshaping before discarding indicate a pronounced depth of planning, as well as curation. Several inventories from sites in the Rhineland, Belgium, and France indicate the replacement of individual elements, such as points in compound tools. Overall, the research of Roebroeks et al. demonstrates a positive correlation between transport distance and the use intensity of an artifact. The authors do not detect big differences between the Middle and Late Palaeolithic regarding the planning of actions and technological organization.

Apart from the detailed criticism of Binford's assessment of behavioral changes in the use of artifacts at the beginning of the Late Palaeolithic as put forward by Roebroek et al., there exist more general limitations to Binford's approach. Although Binford claims to study the transition to modern human behavior not selectively but from a general evolutionary perspective, he remains caught in the dichotomy of non-modern vs. modern or non-cultural vs. cultural behavior. Such an either/or classification always excludes gradual changes, since transient stages are not allowed for. Thus, while he describes planning behavior in the Early and Middle Palaeolithic, he has to reject its validity as implicitly not completely modern. His study of the evolution of planning behavior is rendered even more subjective by vague definitions of what exactly constitutes the existence or lack of depth of planning, tactical depth, and curation in object behavior. While he relates social behavior, such as (communal) hunting or the spatial structure of camp sites, to planning in general, its connection to object behavior, and thus its significance for the three characteristics of object behavior to be studied, remains unclear. He even generally rejects indicators of hunting earlier than the Late Palaeolithic and interprets them as mere signs of carrion scavenging. To support his argument Binford claims that. Clearly structured sites, such as they increasingly occur during the Middle and Late Palaeolithic, are missing in the Lower Palaeolithic; however, more unfavorable conditions of preservation are to be expected with increasing depth of time.

It is Binford's accomplishment to have introduced characteristics derived from tool and object behavior gleaned from archaeological remains into the discussion of human cognitive evolution; this is not the mere adaptation of models and theories from other disciplines to the material implementation of thinking. Overall, however, the evidence put forward in support of his model is not exhaustive and remains selective, contrary to his original intent. The criticism by Roebroeks et al. clearly challenges Binford's interpretation of marked differences between Middle and Late Palaeolithic planning behavior; however, they also do not put forward an own evolutionary prospect.

From Specialized Domains of Intelligence to the Permeability of the Mind

Kate Robson Brown (1993) and Steven Mithen (1994; 1996) choose a very different approach to the evolution of human thinking as expressed in object behavior and archaeological remains – an adaptation of the intelligence domain model developed in psychology. These models of the organization of the human mind, which consider it as a composite of different, independently evolved domains of intelligence, have become increasingly popular since the early 1980s (cf. Chapter 7). Noam Chomsky (1980) views the syntactic capabilities for language processing as tied to a module that operates independently from other intelligence capacities. In his “Theory of multiple Intelligences,” Howard Gardner (1991) defines seven types of intelligence, which he locates in different areas of the brain and which he assumes to develop and work independently from one another. John Tooby and Leda Cosmides (1989; 1992) explain the evolution of different specialized domains with the high adaptation capacities of specific intelligences within Pleistocene hunter-gatherers, as opposed to the overall inertia of general intelligence. As part of the Pleistocene heritage, children seem to possess at least four domains of intuitive knowledge: language, psychology, physics, and biology (cf. Mithen 1996:51). However, according to Patricia Greenfield (1991), children under the age of two years only display general intelligence; it is only later that the different modules develop. Annette Karloff-Smith (1992) perceives many modules as culture specific; the innate intuitive knowledge forms the core from which micro-domains, such as mathematics, develop. In her opinion, it is only with the typically human cooperation of modules that knowledge becomes available outside of its specific field of application and creativity can develop.

While Kate Robson Brown (1993) demonstrates different aspects of a single domain – spatial intelligence – through the study of Early Palaeolithic artifacts, Steven Mithen (1996), in his outline of the evolution of human thinking, *The Prehistory of the Mind,* transfers the model of a fundamentally modular development with later permeability of the domains from ontogeny to human phylogeny. During the course of phylogeny, our modern intelligence developed in three phases. A phase of general intelligence is followed by a phase of the increasing development of specialized domains, which terminates in a phase of connection between the domains, so that now knowledge and ideas can be freely transmitted between the permeable domains. The domains evolving in Phase 2 are interpreted by Mithen, parallel to the intuitive knowledge postulated for modern children, as social, natural historical, technical, and linguistic intelligence (*ibid.*: 64–72).

Mithen classifies modern chimpanzees in between Phases 1 and 2, since they possess a first specialized domain – social intelligence (*ibid.*: 93). He also awards a kind of social intelligence, which allowed the perception of other individuals' intentions and a concept of other social worlds, to the common ancestor of humans and chimpanzees around 6 million years before present (fig. 15). Mithen assumes that by around 2 million years before present the domain of social intelligence was fully developed, while until 1.8 million years before present the technical and natural historical domains emerged, which facilitated the spread of the species *Homo* through large parts of the Old World. Parallel to the relative brain growth, for which he assumes two main phases at 2–1.5 million and 500,000–200,000 years before present, the rapid development of technical and natural historical comprehension was followed by a long static period between 1,8 million and ca. 500,000 years before present, where no major changes occurred. Mithen places the development of linguistic intelligence between 500,000 and 100,000 years before present, but views language largely as a social interaction and thus tied to social intelligence (*ibid.*: 203–7). He assumes that during this time it was not yet possible to talk about technical concerns or the environment, since the pertaining knowledge was still locked within the respective domains (*ibid.*: 140–46). It is between 60,000 and 30,000 years before present that Mithen detects an explosion of culture caused by the opening of the specialized intelligences to the knowledge that until then had been restricted to other domains. This permeability and the flow of knowledge between the domains that characterize Phase 3 are recognizable in bone artifacts and flake industries, burial goods, the colonization of Australia, as well as personal ornaments and art (*ibid.*: 151–53).

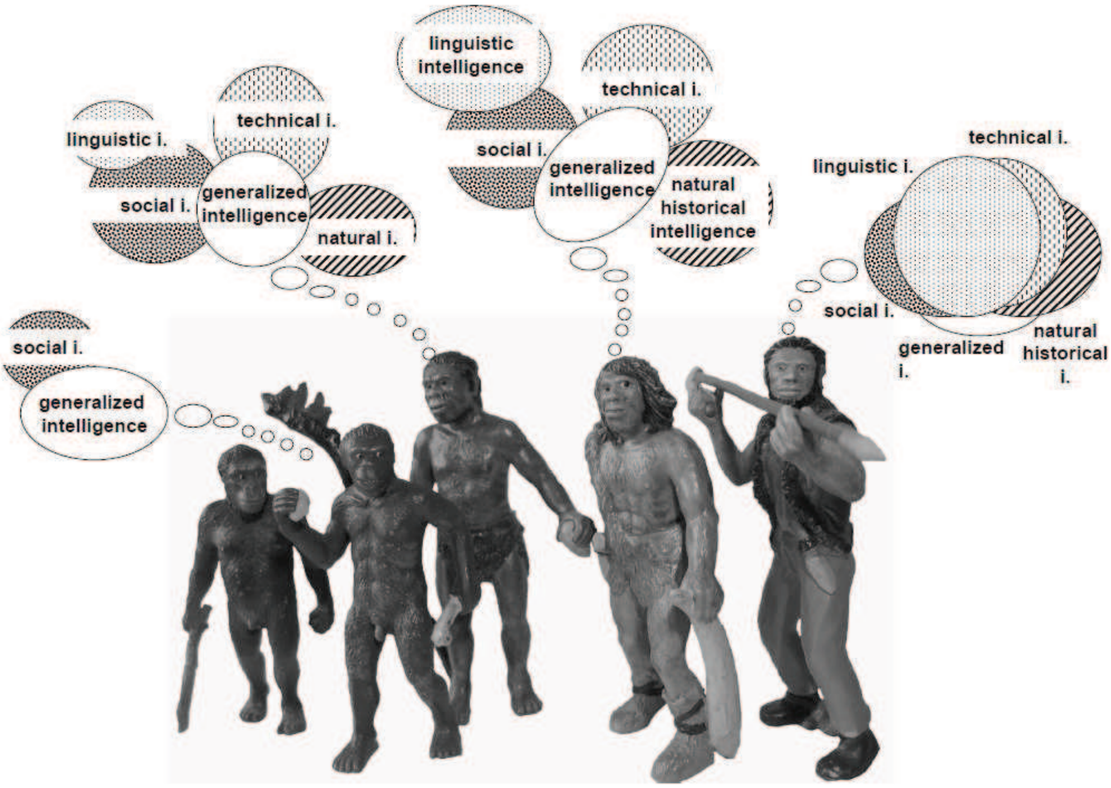


Fig. 15 The evolution of cognition after Mithen (1996). From left to right: Development of a first domain of social intelligence until ca. 2 million years before present; Emergence of different intelligence domains in *Homo erectus*; Emergence of the linguistic intelligence domain in *Homo heidelbergensis* and *Homo neanderthalensis,* from ca. 500,000 years before present. It is only with *Homo sapiens* that the isolated intelligence domains become permeable and able to combine perceptions.

According to Mithen, these artifact categories are missing from the preceding phase of multiple intelligences because they require the collaboration of different intelligence domains. Thus, during Phase 2, bones are considered as parts of animals by the natural historical domain, while the technological domain does not recognize them as a raw material with specific characteristics fit for artifacts. In the dressing of bone hand axes during the Middle Palaeolithic, the bone material is treated and flaked like stone, but is not understood as a material with its own, alternative possibilities. Special and sometimes complex hunting weapons that are attuned to the behavior of specific animals only become possible through the collaboration of the natural historical and technological domains, according to Mithen's model (*ibid.*: 130–31). Burial goods constitute a combination of social intelligence with other domains: natural historical in case of food provisions for the afterlife, and technological in case of artifacts (*ibid.*: 180).

Likewise, art and personal ornaments emerge in Phase 3 as the combinational result of the technological and social modules (*ibid.*: 139). The production of earlier non-functional artifacts, such as the carved nummulites from Tata, Hungary, or the carvings on elephant bones from Bilzingsleben, was facilitated by technological intelligence alone, according to Mithen, since these artifacts still lack any symbolic content (*ibid.*: 160). He views the new cognitive flow between the domains in Phase 3 not simply as an increase in the processing capacity of knowledge but as an actual creation of new conduits between existing domains, so that completely new possibilities of thinking could emerge. As achievements of this now modern thinking he lists science, the belief in the supernatural, and agriculture, among others (*ibid.*: 209).

Mithen transposes a combination of various modular intelligence models established within developmental psychology from ontogeny to the phylogenetic evolution of human thinking. However, the evidence he provides for his model in the form of archaeological remains cannot conclusively prove the reflection of separate intelligence domains, nor their permeability, in object behavior and its material manifestations. While, on the one hand, he notes that the bifacial and Levallois technologies do not differ significantly on a cognitive level, he accepts, on the other hand, the Late Palaeolithic blade technology as an indicator for a new, supra-modular way of thinking. He duly acknowledges indications of early non-functional artifacts, such as carvings and the use use of pigments, while at the same time categorically denying any social or symbolic significance they may have held. Even if his discussion of bone artifacts as the result of the combination of technological with environmental intelligence were comprehensible, the question would still remain why the manufacture of wooden tools, such as the spears or lances from Schöningen, Clacton, and Lehringen, which required the use of whittling, a technique specifically tailored to the working of wood, was not considered as a transgression of domain borders. In a later article, Mithen himself contradicts his assumption of a lack of social function in artifacts before the Late Palaeolithic, when he proposes that Early Palaeolithic hand axes served mainly as a means in the process of mate selection (Kohn and Mithen 1999). Wynn (1993: 311; 1995), on the other hand, detects the combination of social and technological knowledge as early as in the standardization of hand axes during the Acheulean.

Owing to the synoptic view of his study, Mithen does not discuss in detail the possible bases of intelligence within the various groups of artifacts. Consequently, he does not detect any substantial changes in the cognitive organization and potential of humans between 1.8 million years before present and the beginning of the Late Palaeolithic – with exception of the postulated evolution of the linguistic domain at around 500,000 years before present, which cannot be detected through archaeological remains, because no link with technological intelligence existed.

Milestones: Language and Symbol Behavior

Based on a different psychological model but the same archaeological evidence, the psychologist William Noble and the archaeologist Iain Davidson arrive at conclusions very similar to Steven Mithen (Noble and Davidson 1993; 1996). Their social approach is based on the cognitive effects of language and symbolic communication that manifest themselves in behavior and artifacts. In Noble and Davidson's view (1996), intelligent behavior is always interactive and routed in a community. Mental products are exchanged between individuals through the symbolic use of signs within purposeful communication. The basis of modern human cognition is the attribution of meaning, which isolates things and events from the constant flow of perceptions. While chimpanzees seem to have internalized images of prominent objects classified as desirable or menacing, so that they can execute actions related to these objects even if they are not visible, this improved perception of the environment remains individual and not communicable. It is only in humans that the conscious attention to an object or an event, as well as the knowledge of its significance, is divided. Objects, events, and other non-linguistic units do not possess significance by themselves, it has to be construed socially and remains subject to continuing dispute within the community. The communal knowledge of the significance of any given unit is dependent on language (*ibid.*: 128–38).

Communication can only emerge through divided attention. As the point of origin of purposeful interpretation, Noble and Davidson (*ibid.*: 218) suggest the purposeful throwing of objects at prey, enemies, or rivals (fig.16), which may have led, on the one hand, to a natural selection of the neuronal organization of fine motor skills of the upper extremities and hand-eye coordination. On the other hand, the process of aiming itself, without the ensuing throw, may have been recognized as an important component. Thus, the aiming process may have led to the emergence of an iconic, illustrative gesture. In their repetition, these gestures may have left accidental traces, for example in mud, which were recognized as representations of these gestures and imitated. This would have led to the emergence of a new unit of visual attention – the symbol (*ibid.*: 221–24). Once the principle of representative symbols in form of sounds or gestures was recognized, language capability was born: *“As with the notion of something having, or not having, 'meaning,' symbols are either present or absent, they cannot be halfway there.”* The discovery of symbolic signs precludes the slow development of a proto-language. the communal attribution of meaning leads to language, and language allows the description of perceptions, reflection, self-awareness as part of the perceived world and as percipient, memory, and planning for the future. It is only with the help of significance units and concepts that build on them that planning in the sense of designing a sequence of conscious actions to achieve a predetermined goal becomes possible (*ibid.*: 215–16).

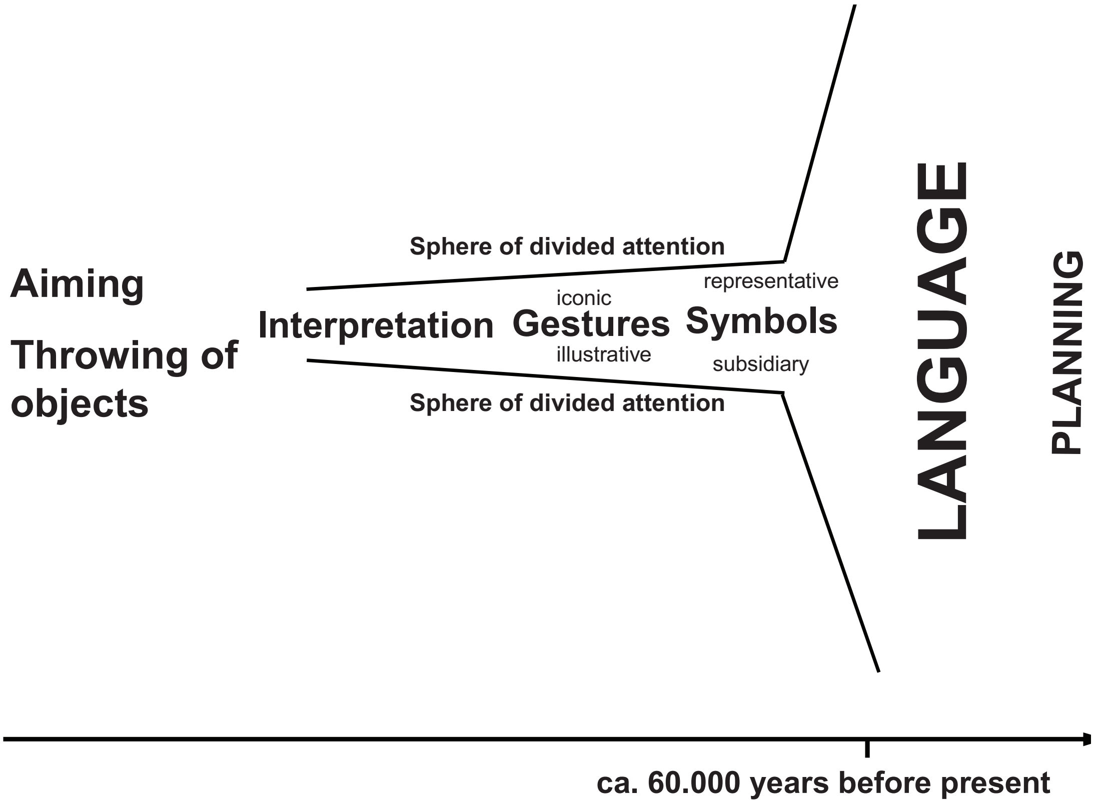


Fig. 16 Cognition model after Noble and Davidson (1996): The development of symbol behavior and language as the precondition of human cognition.

To corroborate their model and as indicators of language and the attribution of meaning, Noble and Davidson present evidence from archaeological inventories that indicates symbolic behavior and planning as defined above. According to their interpretation, the manufacture of lithic tools from the Oldowan, through the Acheulean, to the Mousterian does not display a cognitive but only a technological evolution. While they debate whether Oldowan core tools, such as choppers or chopping tools, were an intended product, the remnants of the flaking process, or the products of no conscious intention (*ibid.*: 167–68), they view the Acheulean hand axes as leftover cores derived through advanced flaking techniques that were not subject to conscious shaping. Neither do Noble and Davidson detect any purposeful production of stone tools during the Middle Palaeolithic: they reject the idea of conscious manufacture of specific flake forms within Levallois technology (*ibid.:* 200) and view the modifications of flakes as mere use retouch (*ibid.:* 193). Only with the transition to the Late Palaeolithic do they identify conceptual variations in the stone tool inventories (*ibid.*: 205). The specific manufacture of other artifacts seems equally dubious to them until some time in the Middle Palaeolithic. In the manufacture of wooden spears they acknowledge the use of tools to produce other tools as a technological improvement, but do not detect any cognitive steps towards the conceptualization of form, which they only grant to the bone and antler tools of the Late Palaeolithic (*ibid.*: 203–4).

While one often-mentioned indicator of planning behavior, the transport of raw materials, displays an increase in transporting distance from the sources during the course of human evolution, the authors attribute this fact to the expanding roaming range of *Homo* groups until the Middle Palaeolithic; it is only with the emergence of modern behavior that they acknowledge a change from the collecting of raw materials as part of other simultaneous activities to the organized, planned procurement of or purposeful bartering for raw materials (*ibid.*: 202–3). Noble and Davidson also view the provisioning of meat as a result of planning not before the early Late Palaeolithic, when big game animals were clearly hunted with traps or composite weapons that required conceptual planning (*ibid.*: 190). The conscious kindling of fire is, in their opinion, as much an achievement of modern planning behavior as the construction of shelters, for which they acknowledge no evidence earlier than the Late Palaeolithic. The postulated burials of Neanderthals they ascribe to specific sedimentation processes in caves; evidence of real, consciously carried out burials in combination with concepts of an afterlife they only find during the Late Palaeolithic and later, as evidenced through rich inventories of burial goods. Artifacts earlier than the Late Palaeolithic, such as hand axes with fossils, that have been cited as evidence for the early use of symbols are viewed with skepticism by the authors, especially since there are no obvious conventions for these signs and repetitive occurrence as evidence for communal use is missing. The use of ocher as a pigment and possible symbol becomes more frequent with the end of the Middle Palaeolithic (*ibid.*: 206–11).

For Noble and Davidson, the most prominent indicator of modern cognition is the colonization of Australia. In contrast to earlier expansions of habitat by various *Homo* forms, which were only an automatic spreading, modern man's colonization of the Sahul region, which encompasses Australia, New Guinea, and Tasmania, could only be accomplished by boat. The construction of boats and their use to traverse large distances indubitably required conceptual planning and language, according to the authors. Archaeological finds in Australia that have been dated up to 60,000 years before present form a milestone, in their opinion, after which modern cognition clearly has to be assumed. While Noble and Davidson do not view the emergence of language as a gradual development but as the fundamental discovery of the possibilities of symbolic significances, they do not assume that all modern behavioral traits that are rooted in language emerged at the same time but became dominant through natural selection (*ibid.*: 173–74). Even if behavior rooted in language is only evidenced from ca. 60,000 years before present onwards, the authors assume that it first started to emerge between 100,000 and 70,000 years before present (*ibid.*: 217).

The Frontal Lobe – Home of Modernity

While Noble and Davidson trace back reflection, memory, conceptual thinking, and planning to language and the latter to divided attention and the attribution of meaning, and thus regard the mind not as individual but socially constructed, Coolidge and Wynn (2001) pick up the model of the phylogenetically evolved frontal lobe of the brain as the seat of reflective and planning thoughts. The development of the cortical frontal lobe was already viewed by Leroi-Gourhan (1984; see above) as a factor in the evolution of modern human cognition. From the observation of behavioral problems in people with damage to the frontal area of the brain, either caused by accidents or congenital, several executive functions of this part of the brain could be deduced: decision-making, formulation of objectives, planning and organization as well as the development of strategies to achieve a goal, and the exertion of control in case of the disruption of planned actions, their obstruction, and their mental integration through space and time or sequential memory. Welch and Pennington (cited in Coolidge and Wynn 2001: 265) subsume the executive functions of the frontal lobe as the capability to retain a matching set of a problem and its solution in order to achieve future goals. In their search for the key factor of modern human behavior, which they locate around the beginning of the Late Palaeolithic, Frederick Coolidge and Thomas Wynn (2001) revisit the hereditary executive functions of the frontal lobe as the crucial characteristic. In their opinion, the transition to modern cognitive capacities is not linked to an anatomical change visible in the skeleton – such as Leroi-Gourhan's “unlocking of the forehead” (1984: 170) – but can be viewed as neuronal re-connections caused by simple changes on the genetical level.

To corroborate their hypothesis, Coolidge and Wynn (2001) search for indicators of some of these executive functions within the archaeological material. The function of sequential memory is the basis of complex action sequences, which they easily detect within the Neolithic. However, even complex flaking sequences, such as those of the Levallois technology, could be explained – after Schlanger (1996) – without resorting to tightly linked action sequences. It is only for between 100,00–50,000 years before present that they accept evidence of a truly multistage technology, such as, for example, in the bone harpoons from the sites at Katanda in the Semliki Valley, Zaire, the dating of which to the Middle Stone Age remains controversial, however (Klein 1999: 439). A second executive function, the suspension of an immediate reward for an action or the action itself, can be detected in the archaeological context at the earliest during the Late Palaeolithic, finding its expression in storage, the cultivation of plants, animal husbandry, or indirect means of capture such as traps. Organization/planning as a third executive function of the frontal lobe coordinates different actions; the transport of raw materials over several kilometers does not meet these conditions, according to the authors, and has to be omitted from the evidence for the thus defined form of planning. Like Noble and Davidson (1996), they cite the colonization of the Sahul region (Australia, New Guinea, and Tasmania) around 60,000–50,000 years before present as the earliest unambiguous product of the planning function of the frontal lobe: *"... and it seems unlikely that such a colonization was unplanned"* (Coolidge and Wynn 2001: 257).

In their study, Coolidge and Wynn do not follow the evolution of cognition as visible in archaeological artifacts but search for the possible cause of a jump in evolution that would explain the changes in artifact inventories at the transition from the Middle to the Late Palaeolithic. Older aspects of the human mind, such as spatial cognition (see Wynn 1979; 1981; 1985), are assumed; thus, the evolution of human thinking took place in several independent steps, the latest of which – the expansion of the executive function of the frontal lobe – led to modern human behavior. While Wynn and Coolidge postulate that, in order to serve as the foundation of a truly evolutionary model, the necessary step towards modern cognition must have been a relatively simple change on the genetic level, they themselves view the change in executive functions of the frontal lobe as *"not attributable to a single dominant gene or recessive genes but to many alleles at different loci which add up to a strong effect on variation in executive functioning"* (Coolidge and Wynn 2001: 257).

The "Dawn of Human Culture" as Genetic Lightning Strike

A similar genetic scenario, which identifies different brain functions as the foundations of human thinking and behavior but also tries to explain the changes in the artifact spectrum at the beginning of the Late Palaeolithic, is laid out in the works of Richard Klein (Klein 1995; 2000; Klein and Edgar 2002). After a number of mutations with selective advantages that form the basis of early cognitive evolution, the last and decisive biological step towards truly modern human thinking and behavior took place around 50,000–40,000 years before present with a neural restructuring that also created language and symbol capacities, according to Klein (2000: 26–27).

Klein and Edgar (2002: 22) view the evolution of the human mind not as a continuous process but as a punctuated equilibrium: long phases of stability are followed by spurts of abrupt change, which in turn are followed by another long phase of stability. Evolutionary innovations occur suddenly and rarely. During the course of human evolution, the authors detect between three and four such spurts (fig. 17), which are supposed to have occurred in East Africa and disseminated with their carriers into other regions of the world.

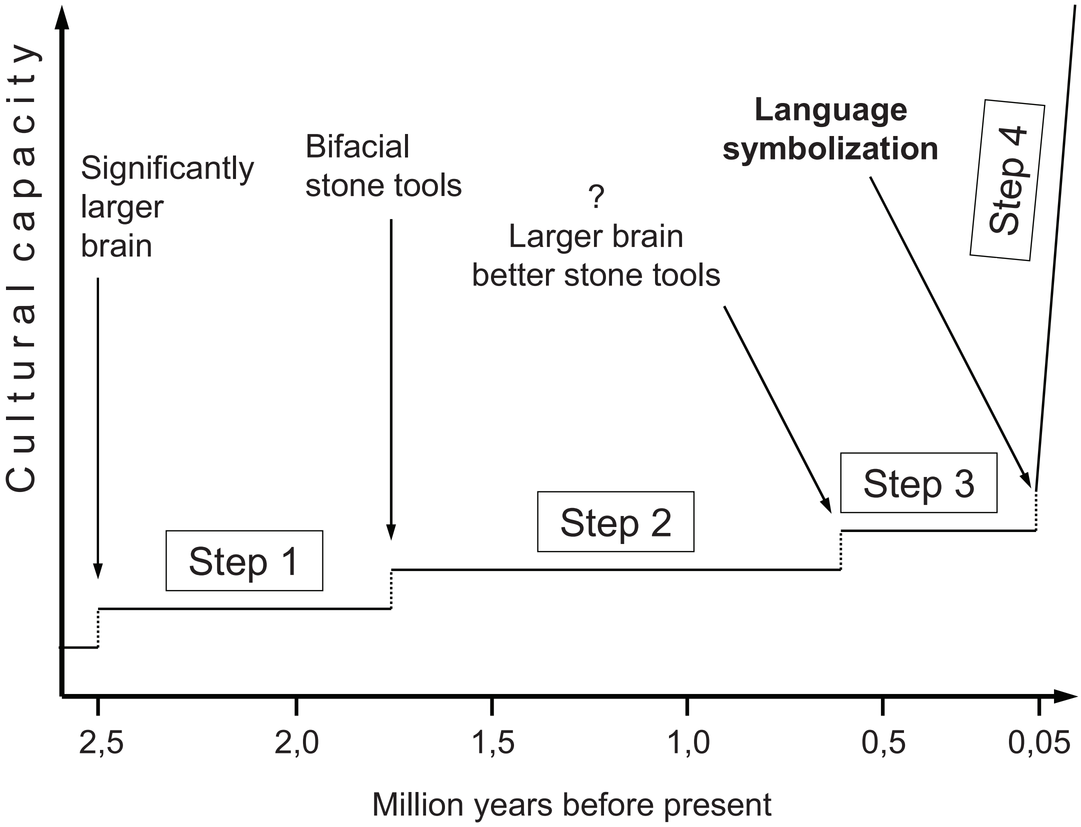


Fig. 17 Development of human cultural capacity after Klein and Edgar (2002). Long periods of cognitive conformity are followed by short phases of genetically triggered changes.

The first step in Klein and Edgar's model – 2.5 million years ago – is characterized by first stone artifacts and a significantly larger brain compared to modern primates. The behavior that can be deduced from the Oldowan sites shows in their opinion no further specific human characteristics; thus, they classify the early *Homo* representatives as "technological apes" (*ibid.*:

92). Around 1.7 millions years before present, Klein and Edgar detect a second step, which is revealed in the modern human physiological proportions of *Homo ergaster* and progressive bifacial stone tools, such as hand axes that have been consciously shaped. The habitat of the species *Homo* is extended to include more arid and seasonal environments, facilitating the first colonization of regions outside Africa.

After a stationary phase in human evolution that lasted at least a million years, Klein and Edgar assume a third step took place around 0.6 million years ago, which is, however, difficult to detect in the archaeological record. Emerging in Africa during this time, *Homo heidelbergensis* is thought to display a distinct increase in brain volume that was accompanied by a qualitative improvement in stone tool industry. While they assume a dissemination of cognitive abilities with H*omo heidelbergensis* towards Europe, Asia remains, in the opinion of Klein and Edgar, a cognitive backwater colonized by the successors of *Homo ergaster,* the different *Homo erectus* forms. Their archaeological argument for East and Southeast Asia's backwardness is based on the lack of hand axes in these regions, first postulated by Hallam L. Movius (1949) and since disproved by the discovery of Early Palaeolithic hand axes in the Bose Basin of southern China (Hou et al. 2000); these regions now can merely be regarded as yielding few hand axes. Concerning the absence of effective hunting strategies, however, Klein and Edgar (2002: 131) detect no major differences between the different *Homo* species. They do not detect other changes in behavior and its cognitive foundations until the end of the Middle Palaolithic. In a preceding article, Klein (2000) does not mention this third stage around 600,000 years before present; instead, he recognizes changes during the Middle Palaeolithic/Middle Stone Age from ca. 0.25 million years before present, such as an increasing variety of flaking techniques, the control of fire, the collecting of pigments, the occasional simple burial of the dead, the habitual hunting of relatively harmless large mammals, and increasingly regionally and chronologically circumscribed stone artifact types.

The last and decisive step in human cognitive evolution according to Klein (1995; 2000) and Klein and Edgar (2002) took place among anatomically modern humans around 50,000 years before present, with the completely modern capabilities of innovation and the manipulation of culture. These are manifest in *“solidly built houses, tailored clothing, more efficient fireplaces, and new hunting technology”* (*ibid.*: 235) and the emergence of art, jewelry, a greater diversity of stone tool types, and formal artifacts made from bone, antler, and ivory (*ibid.*: 261). The cause of this “dawn of human culture” is biological in the authors' opinion; such a fundamental and sudden change could only be explained by a genetic mutation that resulted in a completely modern human brain (*ibid.*: 268–70). The capacity for innovative behavior they relate to language capacity and the evolution of the *FOXP2* gene (Lai et al. 2001; Enard et al. 2002; see Chapter 6).

The Perception of Universal Divine Origin

Hermann Müller-Karpe (2001a; 2001b; 2001c; forthcoming) vehemently objects to the notion that the evolution of human thinking can be explained by biological and, thus, scientifically explicable processes, such as genetic mutation and selection, but he nonetheless arrives at a very similar result to that of Klein and Edgar (2002), concerning the course of its development. Müller-Karpe deems the scientific-factual, explanatory approach that views humans generally as part of the animal kingdom and their capabilities rooted in biological evolution as insufficient. He contrasts this approach with his own, hermeneutically interpreting, understanding approach, in which humans with their culture and deisms are considered fundamentally different from animals (Table 5). At the same time, he combines both approaches in his evolutionary model, where he assumes a first phase of hominization until the end of the Early Palaeolithic that is characterized by genetically determined evolution processes and thus open to scientific explanations, while the subsequent phase of true humans is characterized by integrated cognition in conjunction with a principle of the divine and can only be approached in a hermeneutic-understanding way (Table 6).

Scientific-factual explanatory approach	**Hermeneutically interpreting, understanding approach**
anthropological	humanistic
materialistic	intellectually historical
genetical	historical
nature	culture/principle of the divine
focus on: corporeality, functional artifacts	focus on: mental capacities, functional / religious artifacts
gradual evolution	one-time introduction of a new principle, cultural development
humans are principally like animals	Humans are fundamentally different from animals

Table 5 Comparison of different approaches to human cognitive evolution after H. Müller-Karpe (Haidle in Müller-Karpe et al. 2005).

Thus, in his philosophical-theological interpretation of archaeological remains Müller-Karpe (2001a; 2001b; 2001c; Müller-Karpe et al. 2005) stresses the view that human evolution during the Early Palaeolithic and larger parts of the Middle Palaeolithic should be considered a principally zoological phenomenon that has to be clearly distinguished from the subsequent cultural evolution starting around 40,000 before present at the latest; a view that can also be found – at least partially – in the works of Binford (1989), Mithen (1996), Noble and Davidson (1996), Coolidge and Wynn (2001), and Klein and Edgar (2002). Müller-Karpe sees humans in the true sense of the word as characterized by a mental dimension that precedes and determines any empirical reasoning – the perception of the unified origin of the world. This origin of all things and beings was not considered as an abstract principle but personified as a deity (Müller-Karpe et al. 2005); thus, everything perceivable could be read as divine creation. Through the idea of a common origin, humans construed at the same time a religious basis and a historicity that could give rise to cultural development. After Müller-Karpe, the development of human cognitive capacities, which are rooted in this new dimension of perception, cannot be derived from the gradual progression of animal capabilities; it constitutes a completely new principle of thinking.

Human evolution since the Neanderthals, Middle Palaeolithic	cultural development, historical	humanistically-intellectual historically perceivable mental capacities, functional/religious artifacts
One-time introduction of the mental principle of the divine		
Pre-human evolution until *Homo erectus,* Early Palaeolithic	gradual natural evolution, genetical	anthropological-materialistically explicable corporeality, only functional artifacts

Table 6 Two-phase evolution of human cognition after H. Müller-Karpe (Haidle in Müller-Karpe et al. 2005).

In evidence of his approach of the perception of universal divine origin, Müller-Karpe cites the absolute functionality of Early Palaeolithic stone tools without the emergence of types, the cognitive potential of which he does not see surpassing that of animal tool behavior, and which is supplemented with cultural elements only during the course of the Middle Palaeolithic. In some archaeological remains of the Neanderthals, such as burials and an inferred belief in eternity, he detects early indicators of the religious capacities of the human mind. While he holds true that the stone tool industry in its practicability continued the hominid tradition, he also states with the Middle Palaeolithic the focus shifted from exclusively functional tools to artifact types that were increasingly influenced by cultural or group aspects. According to Müller-Karpe, the thinking consciousness and the perception of the divine then unfolded in Late Palaeolithic art, which should be viewed not as a practical tool in the sense of magical shamanistic practices, but as an expression of the worship of creation. He interprets images of animals and humans as expressions of thankfulness for successful hunts, the survival of danger, the encounter of two people, and pregnancy; hand imprints are an expression of adoration gestures. From the perception of divine universality, Müller-Karpe deduces a new significance of everyday experiences and the consciously accepted dependency from the environment during the Late Palaeolithic. However, in his view the mental capacities of humans also contain the freedom of existential autonomy, which finds its expression towards the end of the Palaeolithic in a changed understanding of the environment, human egoism, and hubris, leading to aggression and wars from the Neolithic onwards. Concomitantly to the differentiated development of the human mind, the harmony of existence was lost.

13 Problems in the Approaches of Archaeological Models of Cognitive Evolution

Despite differing starting hypotheses, the archaeological models of cognitive evolution presented in the preceding chapter all share distinctly similar results (fig. 18). Modern human cognition is linked to a few aspects of behavior, some of which the authors view as closely related: Language (Noble and Davidson 1996; Klein and Edgar 2002), symbolic (Leroi-Gourhan 1984; Noble and Davidson 1996; Klein and Edgar 2002) or specifically religious behavior (Müller-Karpe in Müller-Karpe et al. 2005), planning or reflective behavior (Leroi-Gourhan 1984; Wynn 1979; 1981; 1985; Binford 1989; Noble and Davidson 1996; Coolidge and Wynn 2001), and the free combinability of all knowledge domains and abilities (Mithen 1996). Not all of these aspects are equally considered typically modern; thus, Leroi-Gourhan (1984) assumes first roots of language already parallel to earliest tool production. Mithen (1996) surmises the evolution of linguistic intelligence between 500,000 and 100,000 years before present, where it was initially limited to the social domain and then increasingly associated with non-social contents, thus leading to the modern cognitive structure of permeable domains instead of the former delimited mental areas. Symbol use, a common characteristic of modernity, is often – as a means of communication (Noble and Davidson 1996; Klein 1995; Klein and Edgar 2002) – but not always (Leroi-Gourhan 1984; Mithen 1996; Müller-Karpe in Müller-Karpe et al. 2005) linked to language capacity. The emergence of symbols and "non-functional" artifacts, such as art and jewelry, is additionally explained as resulting from the interconnection of different intelligence domains (Mithen 1996), as the expression of a perceived universal divine origin (Müller-Karpe 2001c; Müller-Karpe in Müller-Karpe et al. 2005), or as the consequence of expanded executive functions of the brain, such as emotion control, consciousness, and reflection (Leroi-Gourhan 1984).

The cognitive elements whose origin and characteristics are linked most closely to modernity and which are studied from the most varied angles are planning, projection and reflective thinking. Leroi-Gourhan (1984) and Coolidge and Wynn (2001) detect anatomical foundations in the development of the prefrontal cortex in *Homo sapiens sapiens,* while Binford (1989) as well as Noble and Davidson (1996) view the capabilities of planning and reflection as directly linked to language capacity. Whereas for Wynn (1979; 1981; 1985) planning manifests in the application of spatial parameters to artifact manufacture, Binford (1989) finds its expressions in the organization and structure of settlement and subsistence behavior, and Noble and Davidson (1996) as well as Coolidge and Wynn (2001) detect it as the basis of a planned communal effort, such as the crossing of the open sea in boats that led to the colonization of Australia.

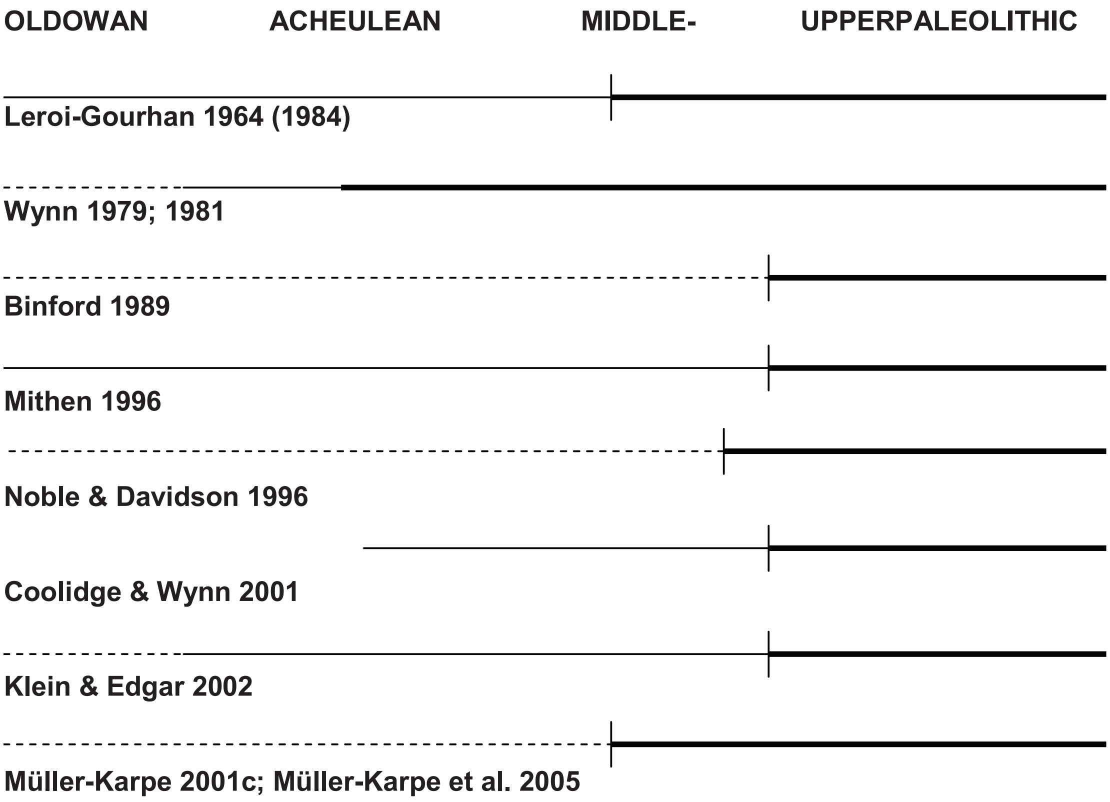


Fig. 18 Comparison of the progression of human cognitive evolution according to different archaeological models.
- - - technological progress, cognitively similar to modern great apes
—— slow cognitive progression, not specifically defined
━━ modern human cognition
| break in cognitive evolution, evolutionary jump

The origin of modern cognition is often linked to physical changes. In these cognitivistic models, the way of thinking is mainly dependent on specific anatomical structures or genetic traits. Thus, Leroi-Gourhan (1984) views anatomical innovations like upright locomotion and the development of the cerebrum as the precursors of modern thinking. Klein and Edgar (2002) take pains to identify a genetic mutation as the trigger of a neuronal restructuring that facilitated language and symbol behavior, while Coolidge and Wynn (2001) assume several genetic changes behind a neuronal reorganization of the frontal lobe. By contrast, those hypotheses that explain the development of new ways of thinking with the restructuring of extant physical elements without fundamental changes have to be viewed as connectionistic in the widest sense of the word. For example, Noble and Davidson (1996) consider the basis of purposeful communication by means of conscious signals to be rooted in a changed throwing behavior, on the one hand, and increased possibilities for divided attention, such as those generated by carrying infants in front of the body instead of on the back, on the other. While according to their model the development of fine motor skills as well as the hairlessness of the mothers, which changed the carrying behavior, are contingent upon genetic changes, the perception of the symbolic significance of an utterance for the whole community is considered as an exclusively mental epiphany. Müller-Karpe (2001c; Müller-Karpe in Müller-Karpe et al. 2005) posits a similar sudden realization of new cognitive dimensions that cannot be ascribed to genetic mutations with his theory of the abrupt perception of a universal divine origin. By contrast, Mithen (1996) stresses in his model the slow development of linguistic utterances based on behavior, from exclusively social domains to others like technology and the environment, and the subsequent interpenetration of cognitive domains. As different as the presented models are, they all are unified in their lack of constructivist components: cultural mechanisms only really function after the emergence of modern cognitive capacities and only then do they influence the implementation of mental capabilities. The historical dimension does not come into play in these explanatory approaches to the early phases of the evolution of human thinking.

The fact that the different models all reach very similar conclusions regarding the course of human cognitive evolution (see fig. 18), with a few exceptions (Wynn 1979; 1981), is not necessarily due to the fact that humans indeed only evolved into reflecting and foresighted beings during the last 100,000 years. The image of primarily technological progress until the middle or the end of the Middle Palaeolithic, which was accompanied by only minor and not further definable cognitive developments, benefits from two methodological problems.

The Ontogenetic Adult Perspective

One possible factor in the prominence of the evolutionary period between 60,000 and 30,000 years before present may be a problem of perspective. During the course of ontogeny, body and mind develop into an adult phenotype under the influence of the natural, social, and cultural environment and according to genetic predisposition. The course of development from the ovum to sexual maturity is largely predetermined, as well as the physical and mental basic set-up of an adult human in comparison to other species. A problem arises, however, when the principle of ontogeny with its fixed tracking is applied to phylogeny. As justification for this transfer, the biogenetic law established by Ernst Haeckel in 1866 is often cited, which states that ontogeny recapitulates phylogeny (Wuketits 1988: 139). However, Haeckels original formulation talks about ontogeny being a shortened and condensed recapitulation of phylogeny;

while most citations stress the repetitive aspect, the limiting factors implied in the condensed state are often overlooked.

Phylogeny consists of a string of many individual developments – ontogenies. The ontogeny of any organism, in turn, is the result of a chain of ontogenies of its ancestors, with channeled evolutionary processes and the transmission from genotype to phenotype under the influence of the natural, social, and cultural environment. However, the script of ontogeny is not merely a summary of phylogeny and follows the latter only in an abbreviated manner; there are qualitative and quantitative divergences during its course. Some processes in ontogeny are speeded up (acceleration), others are slowed down (retardation), and sometimes different developments only apply to individual organs (heterochrony; *ibid.*: 146). In phylogeny, on the other hand, species or group specific characteristics can occur that do not form part of the ontogenies of different or later lineages. This means that ontogeny does not replicate phylogenetic periods of evolution in a chronologically proportional manner and thus does not simply mirror phylogeny. Since human phylogeny is moreover not a simple succession of different species, but displays various side branches, evolutionary dead ends, and ambiguous alternatives of descent, the exact interrelations of which are as disputed as the main lineage, neither can its complete course be parallelized to ontogeny, nor can individual aspects like the emergence of cognitive capabilities in early humans be extrapolated. To postulate, for example, "the brain of a one-year-old who was not even able to talk" (Walker 1996: 81) to be applicable to *Homo erectus* hardly makes sense. The same holds true for the emergence of the executive functions of the frontal lobe of the brain during the course on ontogeny in modern humans (see Coolidge and Wynn 2001), which, owing to the phylogenetically different evolution of the various areas of this brain region (Karnath and Sturm 2002), cannot simply be transferred as a unit into phylogeny.

Furthermore, ontogeny and behavior in particular are strongly influenced by cultural factors in humans. This makes the application of the biogenetic law to the evolution of human behavior, from which the cognitive potential is then deduced, even more dubious. Early hominid forms are not crude and incomplete modern humans, *ergo* defective, but consist of autonomous adult individual according to their species. In the same way that the object behavior among gorillas and bonobos cannot be deemed an aspect of chimpanzee-like tools behavior, but has to be regarded as different behavior (see Byrne 1996), so too can australopithecine, *Homo erectus,* or Neanderthal behavior not be considered as a mere fraction of modern human behavior. The focussing on indicators of behavior defined as modern human within the archaeological context skews the perspective in favor of results that display fully developed, adult characteristics, as opposed to crude or defective characteristics in infantile, earlier periods. Overall, ontogeny cannot provide an exact image of phylogeny, so that extrapolations of the synchronous emergence of different cognitive aspects like language, planning, and symbol use from ontogeny to phylogeny have to be approached cautiously.

Approaches to Artifact Categories vs. Attribute Analysis

A second methodological problem, besides the "adult perspective" derived from ontogeny, is present in dealing with the archaeological record, the questions asked, and the interpretation of findings. In general, a limited number of archaeologically documented artifact categories summarily serve as attributes of modern cognition: blade technology, bone artifacts, burials or burial goods, jewelry, and art (Binford 1989; Mithen 1996; Otte 2001; Tattersall 2001; Klein and Edgar 2002; Coolidge and Wynn 2002; Müller-Karpe in Müller-Karpe et al. 2005). The colonization of Australia complements the catalogue of modern elements mainly derived from characteristics of the Late Palaeolithic (esp. Noble and Davidson 1996). Thus, it is not surprising that the starting point of most archaeological models of cognitive evolution is defined by an assumed cognitive break linked to the emergence of anatomically modern humans around 100,000 years before present at the earliest, but mostly dated between 60,000 and 30,000 years before present. Varying in the specific approach from model to model, an attempt is made to explain the different attributes that are considered modern human as a unified complex via a common causative factor. The actual relations between the attributes and the cognitive bases they indicate remain largely speculative.

In the process of verifying the models advocating a sudden jump in cognitive evolution at or around the beginning of the Late Palaeolithic the same attributes that formerly served in the formulation of the model are considered again. Relatively broadly defined artifact categories are created, the massive occurrence of which then marks the cognitive break. Precursors to the clustered indicators are rejected as not exactly matching the characteristic in question, later developments are subsumed under a period "from the Late Palaeolithic onwards," owing to their relative chronological proximity as opposed to the vast period of evolution that preceded. Thus, early non-functional artifacts, such as the carvings from Bilzingsleben or the reshaping of a chunk of tuff with natural female shape from Berekhat Ram, can be excluded from closer scrutiny as not adequate to the artistic representations from the Aurignacian, such as for example the small sculptures from the Swabian Jura; concerning the argument of the sudden flourishing and varied bone industry the opposite holds true, and early Late Palaeolithic simple bone points are often lumped together with late Late Palaeolithic bone needles, harpoons, and atlatls.

If, however, the archaeological remains from the Early and Middle Palaeolithic, that is, before the assumed break of 100,000–30,000 years before present, are considered more closely, that scrutiny always takes place in predefined chronological periods that are summarily perused for the occurrence of specific artifact categories. Early isolated indicators of new modes of behavior are discarded as not reflecting the general common behavior of the period in focus, and expansions of potential are only recognized as such when their implementation has become universal. The classification of indicators relevant to the changes in mental capacities is often arbitrary or cannot be reconstructed from the articles. For example, Klein and Edgar (2002) do not explain why the more carefully fashioned hand axes from 0.6 million years before present onwards mark a step in cognitive evolution compared to the generally less carefully fashioned ones from the Middle Palaeolithic, while early Middle Palaeolithic evidences of hafting of stone artifacts and thus of composite tools do not, nor why the increased use of bone, antler, and ivory should constitute a distinct extension of cultural capacities. Concerning the archaeological material from the Early and Middle Palaeolithic, most models indeed reconstruct no actual cognitive evolution during the course of human phylogeny. Their main aim is to differentiate modern from non-modern behavior, the latter of which summarily subsumes all behavior exhibited within the species *Homo* before the Late Palaeolithic. These models only serve to manifest the exceptional position of *Homo sapiens sapiens;* they are not models for the phylogenetic evolution of human thinking.

If certain artifact categories are considered as autonomous study units, the reconstruction of developments remains naturally difficult. These artificial types serve as static index fossils that can only be rated qualitatively as present or absent. A quantitative study is usually not carried out. Additionally, if the selection of types is restricted to those that can be related to modern humans and their cognitive modernity, cognitive potential that expresses or manifests itself otherwise cannot be detected in the archaeological record. Instead of specifying indicators for cognitive characteristics, the mode of relationship of which is unknown and does not even have to be causative, an open attribute analysis independent from or permeating artifact categories should be conducted. Its conception should also permit the inclusion of existing, type-related periodizations only after the analysis of attribute development, when the results are integrated within their cultural-historical framework. This would introduce an openness towards results that cannot be found in any of the existing archaeological models of human cognitive evolution.

The following section of this study attempts precisely such an attribute analysis. Instead of documenting the presence or absence of specific artifact categories as attributes of cognitive modernity, I will study a characteristic the fundamental significance of which for the cognitive area of object behavior and its manifestations in the archaeological record has already been established in the first section of this study: the spatial, temporal, and individual dissociation of solutions from problems that cannot be solved in a current situation – thinking outside the box. Comparing animal object behavior with archaeological artifacts from the beginnings of stone tool manufacture to the Neolithic, I will pursue the question if and how far the cognitive option of dissociation, and thus expansion, of problem solutions has changed during the course of human evolution. The interpretation of the results of this attribute analysis will consider the potential otherness of earlier hominid species as well as influences of a cultural-historical dimension of development.

IV The Increasing Distance Between Problem and Solution

The notion of planning, studied by Binford (1989) as the curation of artifacts, the increased circuitous action noted by Köhler (1963: 72–73) in the use of tools, the thinking about the future that Lethmate (1994: 35–36) considers specifically human, the increasing elimination of the body in combination with artifact use as discussed by Alsberg (1922) and Sloterdijk (2002: 179–87), the anticipatory cognition detected by Osvath and Gärdenfors (2005) in the transport of raw materials during the Oldowan, and the increasing depth of planning displayed in the use and manufacture of tools (Haidle 1999; 2000; 2004a; 2004b) are all linked to one and the same phenomenon: the increasing distance between problem and solution. The progressive dissociation of immediate need and its direct fulfillment is one of the main preconditions for the use of objects as media and can be detected in animal tool behavior as well as the archaeological record. It is not a binary characteristic that can only be classified as present or absent but appears as a gradual, increasable feature. Thus, it is well suited as a characteristic on which to study and describe the evolution of an important part of human cognition.

The elimination of the immediacy of problem and solution and the related expansion of extant physical and mental capabilities, where the acting individual exploits the characteristics of suitable objects, is able to increase the action range of tool-using animals enormously. The extension of the problem–solution distance, its progression during the course of human evolution, and its effects are the questions looked at more closely in the following chapters. The basis of this study is a database, found in the appendix, detailing tool use observed in animals and encountered in archaeological remains. First, however, it seems necessary to clarify the definition of the term “tool.”

14 Tools – A Matter of Definition

In ethnographical, ergonomical, archaeological, and zoological literature, the fact that a subject – human or animal – uses an object in order to achieve a goal is recorded differently. What constitutes an object and how it has to be manipulated to be considered a means or medium varies with the respective approach. Even seemingly unambiguous terms like "tool" can denote different things depending on their definition.

Meyers Großes Taschenlexikon from 1900 (Vol. 24: 91) defines tool – *Werkzeug* – as "generally every implement that is used to more easily handle, manufacture, or manipulate an object… According to modern ethnological and (palaeo)anthropological terminology, distinctions are made between tools in the form of simple pieces of material that are used unaltered for a specific purpose only once and implements as pieces of material that are selected, shaped or specifically manufactured, and used repeatedly."

Walter Hirschberg and Alfred Janata (1986) define the terms "tool" and "implement" in their handbook of material culture in ethnology from an ethnological point of view. Their criterion is exclusively the modern human use of the different resources that have to be classified. The term "tool" is rather restrictively used and should denote, according to Hirschberg and Janata, only changes in shape, the irreversible modification of the volume of an object. This definition applies to knives, scrapers, axes, hatchets, adzes, chisels, wedges, hammers, drawing dies, molds, and clamping and grasping tools (anvil and tongs), amongst others. The category of implements is much broader and includes all simple, non-composite auxiliary means, also including water, air, and fire besides objects such as pokers and containers (*ibid.*: 42–43).

From an ergonomical point of view, Christopher Baber defines tools as objects and artifacts that are used to induce changes to other objects in the environment. They facilitate the extension of the user's physical and mental capabilities beyond his restricted individual repertoire (Baber 2003: 1–8). Separate from the tools are other manipulable objects that do not allow flexible use in order to control or refine the effects of changes (*ibid.*: 146); keys, door handles, and gear shifts, for example, do only permit predetermined use, while hammers and screwdrivers, amongst others, can be used in a more differenciated manner depending on the force or angle applied, etc., according to necessity.

From an archaeological viewpoint, these distinctions are irrelevant, since the types of tools that require specified manipulation in order to achieve a predetermined result of use are very late developments and derivatives of object behavior with an open outcome. Joachim Hahn (1993) thus defines tools and implements with special respect to early human archaeological remains. He stresses the importance of distinguishing between natural objects and those relating to humans, as well as the determination of their use. As an umbrella term, he uses "artifacts" to denote the category of all material objects altered by humans: this includes stones moved by humans from one place to another as well as pits, fireplaces, or stone structures, which are clearly fashioned by humans. "Proper artifacts are objects of stone, bone, wood, or other materials that exhibit at least traces of use but typically have been modified in several steps" (*ibid.*: 10). The artificial modification of the artifact's base shape produces a tool, regardless whether the modifications are intentional, such as in retouched stone tools, or unintentional, such as in traces of use. However, within the archaeological record, the identification of tools whose base shapes or natural objects, while having been used, do not display any consequential modifications, is problematic (*ibid.*: 164–66).

Compared to its archaeological use, the definition of tool use in zoology and behavioral sciences has been progressively refined, since the observation of animal tool use allows the documentation of behavior and objects that cannot be detected in the archaeological context and thus neither included in nor excluded from the definition. A basic definition of tool use was established by Jane van Lawick-Goodall (1970: 195), who describes it as the use of external objects as a functional extension of the mouth, beak, hands, or claws to achieve an immediate purpose. By contrast, Alcock's (1972: 464) restricted definition excludes, for example, the intimidation techniques employed by macaques to impress third parties by shaking smaller monkeys and throwing their own feces around. For him, tool use is the manipulation of an inanimate object that was not produced internally, in order to effect improved efficiency in the change of the form or position of another object. Finally, Benjamin Beck (1980: 4–12) cautions that the employ of both preceding definitions could lead to the inclusion of, for example, scratching one's back on a tree as tool use, because tools are not explicitly defined as isolated from the environment. Consequently, he further refines the definition with regard to the object used, the purpose of its manipulation, and the mode of use. In his definition, tool use is the external use of a freely movable object from the environment, in order to more efficiently change the form, position or condition of another object, another organism, or the user himself. In the process, the user holds the tool during or immediately before its use and is responsible for the correct and efficient orientation of the tool.

Based on Beck's conditions, the active throwing of feces can be defined as tool behavior, as well as the the intimidating flourishing of young animals towards aggressive members of the same species. Likewise, the behavior of Egyptian vultures that throw stones at ostrich eggs to smash them open (van Lawick-Goodall and van Lawick-Goodall 1966) can be identified as tool behavior. However, the cracking open of snails by song thrushes, by means of smashing them against a hard surface (anvil) in a so-called “Drosselschmiede” or the throwing of shells by seagulls (Beck 1980:203) and similar actions do not constitute tool behavior, since the molluscs are the targeted objects to be manipulated and not a medium of change. Parker and Gibson (1977) coined for this distinction the term “true tool use” as opposed to “proto tool use.” To be counted under true tool use in the sense of Parker and Gibson's definition, the tool or medium has to be freely movable and needs to be used *actively.* However, if a medium is stationary within the environment and only the object to be manipulated is moved, such as in the case of cracking open hard shelled foodstuff on an anvil among fishes, birds, primates and other mammals (Beck 1980: 126–28; see chapters 17 and 18), or the lancing of an internal abscess by putting the trunk over a dead branch as observed in an Asian Elephant in the zoo (Steinbacher 1965 in Beck 1980: 128), the behavior constitutes proto tool use.

Peter-René Becker (1993: 14) disagrees with these limitations when it comes to the use of anvils, since he considers this behavior to be as complex as the manipulation of freely movable hammers. Likewise, Sylvie Beyries and Frédéric Joulian (1990) detect no marked difference in the complexity of action chains in their comparison of eleven different true and proto tool behaviors in seven animal species. In order to test whether the differentiation of true and proto tool behavior is merely an arbitrary problem of definition or whether it implies existing fundamental differences of a cognitive nature, Lefebvre et al. (2002) compared the frequency of true and proto tool behavior, innovative feeding habits, and different parameters of brain size in birds. Their starting point was the idea put forward by Kathleen Gibson (1986 in Lefebvre et al. 2002) that the relative size of brain structures with key functions in object behavior could allow for a distinction of the two behavioral patterns if they would turn out to exact different cognitive demands. It appeared that bird species that exhibit true tool behavior do indeed show an increase in average brain size; additionally, there is an observable correlation between the number of different tool behaviors per taxon (species, genus, or higher classifying category) and the overall brain size, as well as the size of the neostriatum, a region of the cerebrum in birds that, together with others, is considered to be an equivalent of the neocortex in mammals. The occurrence of proto tool behavior or “borderline tool use” in different taxa, on the other hand, can be deduced mainly from the amount of innovations in feeding habits within these groups, according to the statistical analyses by Lefebvre et al. (2002: 960–63). As a result of their studies among birds it has to be stated that, indeed, *“...three lines of evidence show that true tool users differ from borderline tool users in size of key neural structures...”* (Lefebvre et al. 2002: 960).

Whether these results can be transferred to mammals and primates still has to be verified. Additionally, the results of Lefebvre's group cannot be considered completely unquestionable, since their categorization of different behaviors (Lefebvre et al. 2002: 948–54), and thus the base data of their study, are contested to a certain degree. For example, while they view the baiting of fish with bread and other objects, which Beck (1980) classifies as true tool use, as borderline tool use, they consider the seizing of fishing lines cast by humans in the crow species of *Corvus corax* and *Corvus corone* (Holmberg in Boswall 1977 and Scott 1974; both in Lefebvre et al. 2002: 953) as true tool behavior, together with Thorpe (1963 in Beck 1980) and Millikan and Bowman (1967 in Beck 1980), but contended by Beck (1980: 132) and Boswell (1977). Consequently, the differentiated cognitive assessment of proto and true tool behavior still has to be regarded as an justified assumption, but not as a solid fact backed by independent evidence. Whether the borderline cases collected by Beck (1980: 124–33) in fact do represent true tool behavior in certain instances, will probably depend on the respective interpretative approach. Examples of these borderline cases include sticky “capture blobs” of silk to catch prey in Bolas spiders (*Mastophora*), anvils, scratch poles used for grooming in ungulates, the ritualistic presentation of food or other objects in courtship, nesting, and hatching behavior, or swallowed objects as digestive aids or stabilizers. The identification of tool behavior is controversial in the use of the body's own raw materials (saliva, feces, vomit), such as in the case of baiting seagulls by orcas (Mason 2005) or the “self annointing” of Western European hedgehogs (*Erinaceus europaeus*), who lick strongly fragrant objects or substances like rotting meat or urine, mix it with large amounts of their own saliva, and then spread the mixture on their spines. Further examples, largely not included in tool use in the strict sense, are the washing and soaking of food, as in the famous case of the Japanese macaques of Koshima Islet, orangutans using planks, tree trunks, or boats as floats, and the bridging of gaps by members of the same species in howler monkeys, ants, and orangutans.

Animal constructions such as nests, burrows, bowers, hives, nets, traps, dams and lodges (Collias and Collias 1976; von Frisch 1974), as well as stores of provisions are all excluded from the definition of tool use mentioned above. While they represent animal artifacts, even the most complex and decorated among them, such as the courtship ritual constructions of bowerbirds and some birds of paradise (Borgia 1985; Borgia et al. 1985; Diamond 1982; 1987; Pruett-Jones and Pruett-Jones 1988; Veselovsky 1978) are no actual media to change the form, position or condition of other objects. The individual elements of construction, decoration, and bolstering are used and incorporated as building materials and thus do not serve as tools or media.

In order to establish a database of animal, early human, and modern human behavior (see Appendix) and to enable the following comparative studies, I have generally followed Beck's definition of tool behavior. Thus, tools as media are defined as freely movable objects that are used in a controlled manner with hands, feet, beaks, mouths, trunks, and tails as an extension of these in order to change the form, position or condition of another object, organism, or the user himself. This definition can be applied relatively readily to animal tool use and its employed artifacts, since generally the use of these objects has been observed directly. Thus, even inconspicuous objects that show no obvious traces of use can be classified as tools. In the archaeological context, artifacts classified as not used according to this definition, such as production debris, post holes, layers of flagstones, fireplaces, and burials, amongst others, have to be separated from implements. I will do this as far as possible, but I will also – where appropriate – consider the additional information bearing on production technology or usage context of tools employed inherent in these artifacts in order to complement the picture of human tool behavior in prehistory.

Tool or Toy?

The following comparative studies of object behavior incorporates, besides tool behavior in the strict sense, interactions with objects or media in a playful or artistic-symbolic context, which usually are not considered as tool use because of their not apparent functional context. The basics of the discussion whether tools and toys can be equated or have to be separated are found in Jean Kitahara-Frisch (1977) and Benjamin Beck. There, play is characterized as an action or actions without economically useful results, *"...often seen not to be practiced as a means to an end but to constitute rather an end in itself. The center of interest is process rather than a goal (Miller 1973)."* (Kitahara-Frisch 1977: 61).

The term tool, by contrast, is predominantly centered around subsistence behavior. This limitation is caused by the general connotation of tool with work and effective and efficient behavior. For example, Nishida (1974 in Kitahara-Frisch 1977: 62) considers object behavior to be tool behavior only if it can be considered imperative for survival. Tool behavior improves the odds of survival and thus of reproductive success, while play is not dominated by selection pressure. In the search for the difference of humans and their evolution (e.g., Oakley 1963; Lancaster 1968), tool use within the context of subsistence and intra- and extra-species competition can be used as a simple but easily conceivable as directly adaptive characteristic, all the more so, since both behavioral complexes can be construed from the archaeological record. The discussion of the emergence and assertiveness of new genera and species during the process of hominization, as well as the extinction of human ancestors and side branches is still generally characterized by the focus on immediate subsistence concerns.

In a comparison of the reproductive success of chimpanzees and baboons in Gombe, Benjamin Beck (1975 in Kitahara-Frisch 1977: 59) realized that even fully developed animal tool use in a subsistence context does not necessarily lead to a significant advantage in competition. Thus, Kitahara-Frisch poses the question whether tool use in chimpanzees does indeed fulfill the same functions as those he assumes unquestioningly for early hominids, namely *"exploiting and adapting the environment as an answer to the biological needs of the tool-makers"* or whether, by contrast, it has rather to be seen generally as a form of pastime, also employed in the foraging for food. However, he assumes that play and subsistence contexts cannot be separated and views the real significance of object behavior less as connected to the actually mastered tasks, but as an expression of an underlying cognitive development: *"How can play be told apart from subsistence strategy, a toy apart from a tool*?" (Kitahara-Frisch 1977: 63).

Many of the antagonistic (overawing or intimidating behavior, defense) or subsistence-related behaviors including tools are already anticipated and practiced in the social or solitary play of young animals and are resumed by adolescents and adults as a non-functional pastime (see examples in Beck 1980: 40, 47, 56, 67, 75–76, 78–81, 83–85, 90–92, 94–95, 100–102, 104–5, 109, 111–12, 114, 154–55). Köhler (1963: 50–71) views object behavior of his chimpanzees outside experiment situations as play, rather than the accomplishing of tasks, although an objective differentiation between subsistence and play contexts is not always possible. To elucidate this point, Kitahara-Frisch (1977: 61) chooses the example of dipping bread into a cup of water in order to then suck the sponged water out of it, after most of the thirst has already been quenched by taking large gulps: *"...the behavior seems to be an end in itself and not only or always an answer to a need."* Matsusaka et al. (2005) also report tool use unessential for the quenching of thirst by scooping or sponging water among wild chimpanzees (*Pan troglodytes schweinfurthii*). Young animals, up to an age of ten years, of the M-group in Mahale used tools at bodies of running water, scooped water from tree holes even during the wet season, and occasionally incorporate other elements of play into this behavior. It has to be noted here that this mode of interaction with objects is not limited to animals; numerous object activities among modern humans arise from the joy of handling objects and are only subsequently reinterpreted as economically useful or subsistence-problem-solving activities.

Besides the practicing of tool use in a playful context among young animals and the transfer of tool use from a primarily subsistence-related context to other areas of behavior among adolescents and adults, some animal species – especially primates – demonstrate intensive occupation with objects from their environment that cannot be related to subsistence or antagonistic behavior. Huffman (1984) and Huffman and Quiatt (1986) describe eight different subspecific forms of stone-handling, a form of solitary play, among Japanese macaques (*Macaca fuscata*), which otherwise display explicitly functional tool behavior on a negligible scale. Bonobos (*Pan paniscus*) also feature intensive and sometimes, in social play, very differentiated tool use, where for example while playing tag the object of play can attain tool status through its use as a communication signal. In these situations, the animal to be tagged carries a stick; if it drops the stick, the play is interrupted, if it takes it up again, the play is resumed; if the animal is caught, the stick changes ownership, although possession of the stick does not seem to be the overall goal. When the group moves on and the play is suspended, the object of play is discarded. Ingmanson (1996: 201) notices that in these situations *"...the stick enhances the play, signalling to other players information and focusing attention on the activity itself."*

Whether complex, flexible tool use is possible without preceding playful interaction with objects during individual ontogeny, is a problematic question, owing to the lengthy conceptual and sensorimotor learning processes involved even in basic object interaction (cf. Connolly and Dalgleish 1989; Beck 1980: 174–76). However, I consider the exclusively functional interpretation of play as merely the practice version of alleged subsistence behavior as too narrow. As the examples above demonstrate, play can assume a major role in the perception, experience and affirmation of one's self and one's social community, where objects can definitely be used as media and, thus, tools. Since from this perspective playful context and tool behavior cannot be separated, I have included the playful interaction with objects into the comparative analysis of animal and human object behavior. This choice is deliberate also regarding the fact that the archaeological interpretation of artifact inventories precludes the context of play, since its attestation is by far more difficult than that of important functions in the strife for everyday survival, such as subsistence and, less frequently, defense or overawing behavior. The cases considered in the following consideration of the evolution of object behavior are compiled into a database, the tabulated version of which can be found in the appendix.

15 Comparative Studies of Human and Animal Object Behavior

Detailed studies of tool use and manufacture among animals as opposed to humans are few and far between. Even rarer are attempts to not only contrast the tool behavior of humans and animals, but to compare these instances from a technological and conceptual point of view. In the search for the reasons behind this lack, Thomas Wynn (1990) primarily cites different science traditions, which already differ in the collection of data, but even more so in their analysis and interpretation. The biological-ethological approach ("natural historic" in Wynn) frequently describes spontaneous animal tool *behavior,* often not evoked during experiments, in an anecdotal manner, without interpretation or generalization of the primary sources or the fitting of these sources into a theoretical background. Usually, thus far unknown phenomena are reported, while the initial phase of the observed behavior remains as unobserved or neglected as its technological components. Especially the material basis of the behavior, that is, the tool as such, its base material, and its manufacture, is often just grazed. Systematic analyses of individual known behaviors are rare (e.g., Boesch and Boesch 1983: 1984a; 1984b; McGrew 1974; Uehara 1982) and, logically, confined to a few frequently observed behaviors among intensively studied species. Interpretations focus on ecological, adaptive, social, motivational, or cognitive contexts of the respective behavior. It is only recently that material-technological questions increasingly become a focus of attention (e.g., Fox et al. 1999; Hicks et al. 2005; Hunt 2000a; Hunt and Gray 2004; Sanz et al. 2004).

Due to the relatively short chronological range even of long-term studies, one can only speculate about the evolutionary history of animal tool behavior (e.g., Nishida and Hiraiwa 1982). The first archaeological excavations of the material remains of animal object behavior (Joulian 1996; Mercader 2002) had to start with the study of a site known through the direct observation of this behavior. The detection of animal tools outside a narrow chronological context of action will remain difficult, since modifications to animal tools are relatively unobtrusive, their mostly organic raw materials are highly perishable, and the identification and attribution of animal origination pose a double problem. Thus, it will probably remain impossible to write a prehistory of chimpanzees. While there exist occasional discussions of innovative behavior in primates (e.g, Kummer and Goodall 1985; Huffman and Quiatt 1986) and its dissemination beyond individual learning processes (e.g, Boesch and Tomasello 1998; van Schaik et al. 2003; Whiten 2005), approaches to study technological change are lacking. Syntheses of tool behavior on a group (e.g, Whiten et al. 1999; van Schaik et al. 2003) or species level (e.g., Beck 1974; Huffman and Quiatt 1986; McGrew 1991; 1992; Byrne 1996; Hohmann and Fruth 2003) often display astonishing differences regarding the situational context. However, species-specific technological comparisons do not exist, as already Wynn (1990) bemoans. Even the otherwise extensive study of tool behavior among chimpanzees by William McGrew remains rather uninformative regarding the material and technological aspects.

By contrast, archaeological studies of (early) human *tool* behavior are definitely dominated by the consideration of material remains. Ethological aspects, such as the mechanisms and actors in the transmission of traditions, remain peripheral, since they cannot be observed directly and are difficult to extrapolate: *"L'analyse des seuls outils transformés renvoie trop souvent à un aspect cognitif individuel et non social."* (Joulian 1998: 72). Primary sources generally introduce new sites, although occasionally individual artifact types are presented that so far were not documented in a region or period, and which are very rarely completely new. Archaeological primary publications mainly deal with artifact classes and their degree of standardization, and often only summarily with their functions, the raw materials used and their provenance, production processes, and artifact assemblages. The group-specific context of behavior is stressed versus an individual, ecological-adaptive perspective. This "supra-organic tradition" considers technology as a quasi autonomous cultural system and attaches great importance to the idea of technological progress with increasing complexity and efficiency (Wynn 1990: 103–4). While this tradition incorporates a general concept of development, as opposed to the natural historical approach, theories about the course and the mechanisms of this process are still only rarely substantiated. And while primate tools are dealt with without the discussion of technological change, early human tools are only considered from a human-technological perspective, without the inclusion of animal data from the natural historical approach for comparison or integration. Thus, according to Wynn (1990), none of these schools of thought can provide an approximation to the differences of human and animal tools.

That the line does not necessarily have to be drawn between the biological-ethological (natural historical) and the archaeological-technological (supra-organic) approach, and thus between non-human primates and early human tool cultures, is demonstrated by Michael Tomasello (2002), who transforms the theoretical-methodological dichotomy criticized by Wynn into a phylogenetic difference. As a starting point of actual human behavior, he looks for "the comprehension of intentionality and causality" (*ibid.*: 29–37) as a new cognitive capability, which possibly occurred for the first time as late as 250,000–200,000 years before present, and only which facilitated various technologies as cultural systems and the increase of complexity and efficiency by cumulative cultural evolution. If one follows Tomasello's argument, the supra-organic, technological approach cannot be applied prior to the evolution of this comprehension of intentionality and causality, because before that no major technological systems nor their change existed.

Yet, there exist attempts to combine both approaches, whereby usually archaeological-technological questions are applied to primatological data, while the transfer of ethological approaches to tool behavior onto archaeological data has thus far attracted only limited interest, owing to insufficient data. A pioneer of this interdisciplinary direction is Wright (1972), who in his study of the five-year-old orangutan Abang reached the conclusion that australopithecines were generally cognitively capable of learning how to manufacture stone tools through the observation of *Homo* individuals. In practice situations, he first showed the ape how a tied-up box containing food could be opened with the help of flakes. In a second phase, he demonstrated how to produce a flake from a fixed core; Abang proved capable of learning from a different species (*Homo sapiens*) in both situations. While Wright's study deals with fundamental cognitive capacities, Kathy Schick and Nicholas Toth (1993; Toth et al. 1993; Schick et al. 1999) employ long-term stone flaking experiments with the bonobo Kanzi to monitor the development of his manual and conceptual capacities, as well as the comparability of the thus acquired artifacts to Oldowan inventories.

Besides experimentally generated capabilities, tools created by chimpanzees in contexts without human influence were also studied with regard to their inherent potential. Thomas Wynn and William McGrew (1989) also employ Wynn's approach of the transfer of Piaget's theories to archaeological artifacts (Wynn 1979; 1981) in their study of chimpanzee tools. From a comparison of the cognitive complexity manifest in these tools, in the sense of Piaget, they reach the conclusion that the cognitive capabilities of Oldowan individuals did not surpass that of modern chimpanzees, except in the transport of raw materials. However, they state that their existing cognitive potential is not used by modern chimpanzees to the extent apparent in the preserved Oldowan tools. A similar result is presented by Frédéric Joulian (1996), who derived *chaînes opératoires* from various tool actions, such as nut-cracking with a hammer among chimpanzees or the manufacture of an Oldowan chopper. In a comparison of chimpanzee and early hominid behavior that considers archaeological-technological as well as primatological-ethological questions, Adriaan Kortland (1986) notices that no indicators of a functional equivalence, similar motion sequences, or analog motivations could be found in the use of stone tools of both groups.

In a study of eleven different tool use behaviors, which were observed among seven different animal species, from an assassin bug to chimpanzees, Sylvie Beyries and Joulian (1990) reach the conclusion that the complexity of *chaînes opératoires* cannot be correlated with the zoological classification of the species. However, the number of individual actions and action phases hardly equals the complexity of the underlying *schéma conceptuel* (Beyries and Joulian 1990: 24). In order to approach the evolution of this conceptual potential, I will attempt to sketch the development of the expansion of the problem-solution-distance in a comparison of animal and (early) human tool behavior in the following chapter.

16 The Study of Problem-Solution-Distance: Basics

This present study of the expansion of the problem-solution-distance during the course of human evolution has to be placed in the theoretical sphere of Cognitive Archaeology. It has risen from deliberations on object planning behavior (Haidle 1999; 2000; 2004) and is based on a compilation of human and animal tool behavior. Its point of departure is the tool, that is, the medium that is employed in the solution of a problem. In order to illustrate the distance between problem/need and solution/satisfaction, I use a further development of the *chaînes opératoires* method. Since the extended course from the perception of a need, through different phases of problem solving, to its final satisfaction can only be partially and indirectly ascertained in the artifacts, the approach to the reconstruction of these processes can only be hermeneutic-understanding.

In choosing tool behavior, I have singled out a definitive type of behavior, which occurs in many species of the animal kingdom, though often only isolated. The amount of animal tool behavior is still documented rather clearly and widely, so that an overview (see Appendix) can be attempted and then contrasted to a selection of the vast multitude and variation of (early) human tool behavior. The compilation of archaeological tool types – from the earliest stone tools to the elements of the Neolithic – and their underlying problem solution strategies took place according to important types that in our modern perception define whole periods, as well as significant innovations and interesting exceptions. However, the whole process can be transferred to any other given animal or archaeological tools, so that the theories of the course of the expansion of the problem-solution-distance advanced here can be tested and possibly disproved at any time.

The study's intention is to outline the evolutionary course of a remarkable and typical aspect of human thinking, while at the same time no causal explanation is intended. The archaeological attestations are not subsumed into broad chronological periods, but are compared diachronically according to their more or less exact dating. Since chronological periods do not constitute natural phases and do not coincide with the contemporary units they describe, but are mere auxiliary constructions that are meant to facilitate an organized overview, it would be counterproductive to use them as the foundation of a study that attempts to sketch the course of developments. A subsumption of the results according to chronological periods is only useful subsequently, as a means of facilitating comprehension.

Additionally, no strictly quantitative comparison of the frequency of certain phases of problem-solution-distance is attempted. For one, this would by far go beyond the scope of this study, which consequently would have to be limited in its chronological or geographical range. Secondly, while every expansion of the problem-solution-distance and its underlying object planning capacity leads to an expansion of potential tool behavior – i.e., new and innovative behaviors can occur, but do not necessarily have to – the actual use of behaviors among humans, and probably also chimpanzees and orangutans, is group-specific, dependent on culture and environment, and finally also individual. The inference of behavioral potential, and possibly a classification into more primitive or progressive, or more or less intelligent populations, according to the different manifest repertoires of tool behavior within individual groups is not possible.

Extreme caution has to be exercised in statements about the cognitive capabilities of a group regarding archaeological sources. In these situations, results obtained have passed through a double filter: a) generally, only thought processes that have materialized into artifacts are open to scrutiny; b) many material implementations are not or only badly preserved, or geographically very diverse, and, especially in the early phase of the Early Palaeolithic, barely documented. In spite of this double filter of materialization and preservation/ location/ documentation and its ensuing problems, statements regarding the cognitive development derived from tool behavior are possible, since already minor variants of the cognitive foundations or their application can find their expression in the artifact spectrum. Thus, it is possible to outline at least the broad course of the expansion of the problem-solution-distance and the development of object planning behavior by mapping the first materialized and documented appearance of a behavioral variation.

I assume that the cognitive potential of a species follows the same normal distribution as other capabilities. It follows that the occurrence of a tool behavior at one site implies that other individuals or groups within the same species are or were generally cognitively capable of the same behavior. Overall, however, it is only possible to ascertain a secure point in time *post quem* an expansion of potential can be assumed, though that point not necessarily indicates the first appearance of the capacity. David Whitley (1998b) stresses the fact that the intellectual potential of the modern brain was realized only long after its assumed first manifestations, and even possibly has not been realized fully until this day. He describes the human mind as clearly structured but with a lot of space for variability within this order, so that neuroanatomic determinism an be ruled out. The question why existing potential is not or only partially realized, or why one group realizes it when another does not, has to be traced back to ecological, social, cultural, and individual factors (see, for orangutans, Fox et al. 1999: 112–113). The approach chosen for this present study thus describes an evolution, but is not evolutionistic in the sense that the increasing differentiation of cognitive possibilities in tool behavior and the associated planning capability necessarily have to lead to an expansion of the actual behavioral repertoire.

The question which fossil *Homo* species in particular is responsible for which form of tool use will not be considered here, owing to a number of problematic attributions. Consequently, and also due to the difficulties arising from the summarizing of long periods of time mentioned above, a cognitive characterization of *Homo erectus* or the Neanderthals is not undertaken. *The* typical representative of a fossil human species that spans hundreds of thousands years does not exist; he can only be construed in retrospect, with all strengths and weaknesses inherent to such a model.

The Database

The compilation of animal tool use found in the Appendix attempts to furnish a more or less complete overview of the currently known forms of behavior involving true tools (true tool use in the definition of Parker and Gibson 1977). Owing to the vast amount of information, entries in the database incorporate, amongst others, already existing compendia (*inter alia* Beck 1980; Becker 1993; Chevalier-Skolnikoff and Liska 1993; Jordan 1982; Lefebvre et al. 2002; McGrew 1992; van Schaik et al. 2003; Whiten et al. 1999; 2002) without always verifying individual entries against their primary sources. However, to allow verification for those interested, the sources cited in the compendia are appended. It is only possible to examine individual cases from this vast database during the following chapters; quite a number of cases have not been processed further. Nevertheless, the complete database is appended, since it provides an overview, serves as a tool for further study, and provides inspiration for future research.

The database is organized according to species groups (gastropods and mollusks, insects and crustaceans, fishes, birds, mammals, primates, hominidae). Amongst amphibians and reptiles, no tool use has been observed so far. Within those groups, the different tool uses amongst a species are listed in alphabetical order according to the Latin name of the species. A data set further incorporates information on the observation circumstances (wild and uninfluenced to trained in experiments), an artifact category, such as for example lever, probe, or sponge, and a description of the tool behavior and the artifact, as well as possible modifications thereof, wherever possible. The classification of modifications follows that of Beck (1980), which includes the following categories: detach (e.g., a branch from a tree), subtract (e.g, defoliate, debark), add-combine (e.g., stacking of several boxes), and reshape (e.g., sharpening, unraveling). The data set is completed by the functional context of the tool use (personal hygiene, subsistence, play, parental care, defense, overawing, stimulation). The occurrence of certain forms of behavior in different contexts amongst a species is reflected in the respective existence of multiple data sets. Additional elements of the database are a list of up to three variants of raw materials for the same tool, as well as the solution unit. This last entry describes whether the tool was *not* modified, modified *directly* by the subject by means of hands, teeth, fingers, or claws, or modified *indirectly* with the help of another tool (cf. Haidle 1999; 2000; 2004). A final entry field lists the pertaining literature.

An extension of the database to incorporate archaeological artifacts was – contrary to my initial plan – not undertaken; without chronological or geographical limitations, the amount of data would be endless. While possibly still feasible for the early and middle Early Palaeolithic, the stream of data from the Middle Palaeolithic onwards would not be manageable without dams and barriers. Finally, to incorporate only a select collection of archaeologically documented tool behavior into the database seemed hardly logical, since the selection process has to remain arbitrary if the main goal is merely to increase the number examples cited in the text, the latter of which are, however, selected for specific reasons and thoroughly explained.

The Method: Cognigrams

In a descriptive study, Frédéric Joulian (1996) compares the complexity of tool behavior involved in the cracking of *Panda oleosa* nuts among chimpanzees with the manufacture of Oldowan choppers using the concept of *chaînes opératoires* (cf. Chapter 11). He dissects both tool actions into individual steps of action – the smallest units of action – and combines a number of them into larger segments; the exact delimitation of these phases remains unclear. From this comparison, Joulian – such as others before him (e.g., Wynn and McGrew 1989) – reaches the conclusion that the action chains of these two forms of behavior differ only minimally, with the cracking of nuts probably even being the somewhat more complex action (fig. 19). This result contradicts the often voiced opinion that the manufacture of even a very simplistic tool by means of another, secondary tool and its later use constitutes a fundamentally different cognitive process than an action involving a tool produced only by individual physical means, however complex that action may be (e.g., Kitahara-Frisch 1993; Haidle 1999; 2004b).

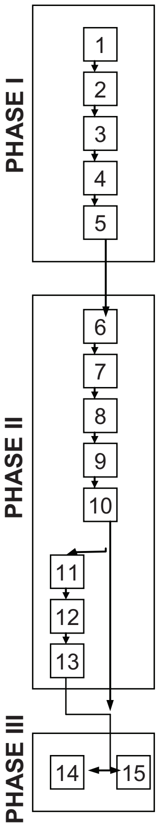
In the search for possible reasons behind the lack of complexity in Joulian's description of the chopper manufacture action chain, it has to be noted that, while nut cracking constitutes the satisfaction of a need (food) experienced by the subject directly, the description of the action chain in the chopper example ends with the use of the tool itself and thus before the actual direct satisfaction of the subject's need. This circumstance could be explained by the fact that this continuation of the action chain to the final solution of a direct physical or psychological problem experienced by the subject was simply overlooked. It could, however, also mean that the manufacture and use of a tool are indeed viewed as a concluded chain of action.

Cracking of *Panda oleosa*-Nuts
(after Joulian 1996)

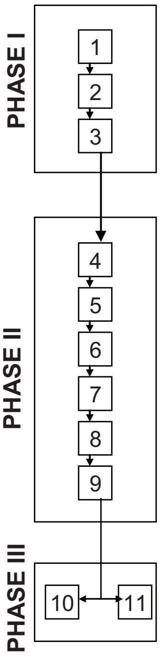
PHASE I: Gathering nuts
1. Selection of tree / anvil
2. Search for hammer stone
3. Transport to anvil
4. Gathering nuts
5. Transport to anvil

PHASE II: Opening nuts
6. Positioning individual
7. Positioning nut on anvil
8. Taking hammer
9. Hammering (several times)
10. Putting hammer aside
(if nut is open: Phase III Eating)
11. Repositioning nut
12. Hammering
13. Putting hammer aside

PHASE III: Eating nuts
14. Direct consumption
15. Indirect consumption



Knapping of an Oldowan chopper
(after Joulian 1996)



PHASE I: Gathering rawmaterial
1. Search for rawmaterial
2. Search for hammer stone
3. Transport to atelier

PHASE II: Knapping tool
4. Positioning of the individual
5. Positioning of rawmaterial and hammer
6. Knapping (debitage)
7. Turning the core
8. Knapping (retouch)
9. Knapping (flake)

PHASE III: Use of the tool
10. Use chopper
11. Use flake

Fig. 19 *Chaîne opératoire* of the cracking of *Panda oleosa* nuts among chimpanzees (*Pan troglodytes*) in comparison with the action chain of the manufacture of Oldowan choppers: Graphs produced according to Joulian's description of action chains (1996) following the usual graphic criteria (cf. Chapter 11).

However, each of our conscious and unconscious actions (excluding reflexes) originates from a subjective point that demands positive or negative feedback. Choppers and flakes are not manufactured by reflex, but are produced as tools originating from an intention that is based on the subject's perception of an actual need; and this basic problem demands a solution. In order to better demonstrate the different levels of requirement, the problem perception underlying the actions has been incorporated into the cognigrams (figs. 20–21; cf. fig. 22).

Cracking of *Panda oleosa* nuts

0. Perception of basic need: hunger
0a. Perception subproblem 1: need of a nut
0b. Perception subproblem 2: need of a tree / anvil
0c. Perception subproblem 3: need of a tool

PHASE I: Selection of tree
1. Selection of tree / location of anvil

PHASE II: Search for tool
2. Search for hammer

PHASE III: Transport of tool
3. Transport to anvil

PHASE IV: Gathering nuts
4. Gathering nuts
5. Transport to anvil

PHASE V: Use of tool / Opening nuts
6. Positioning of individual
7. Positioning of nut on anvil
8. Taking hammer
9. Hammering (several times)
10. Putting hammer aside
(if nut is open: Phase VI Satisfaction)
11. Repositioning nut
12. Hammering
13. Putting hammer aside

PHASE VI: Satisfaction of need
14. Direct consumption
15. Indirect consumption

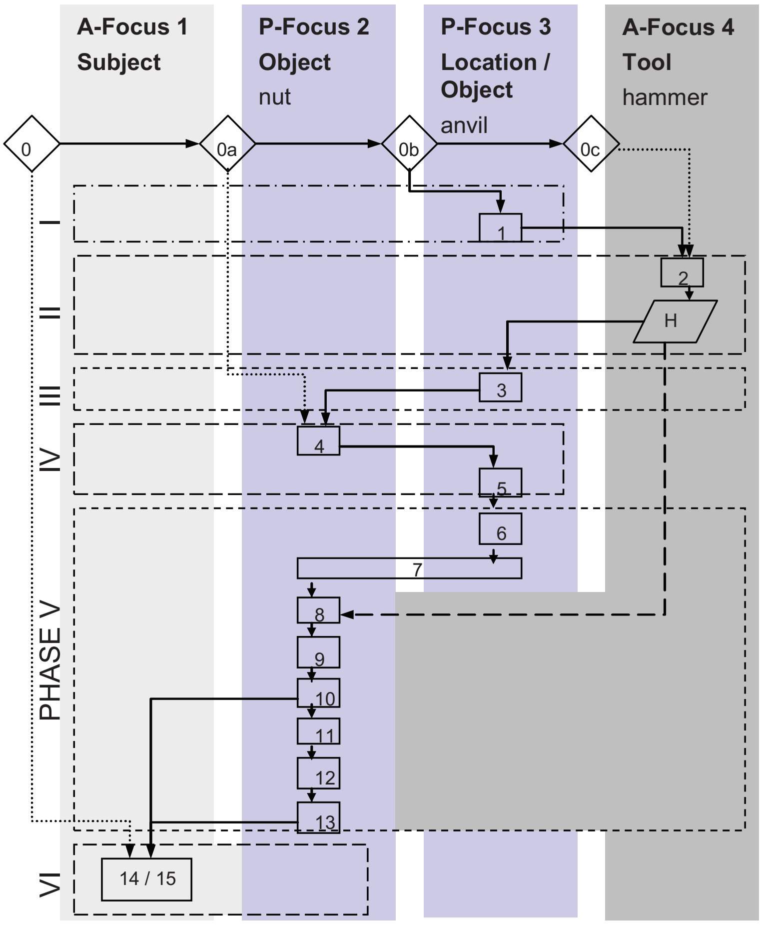
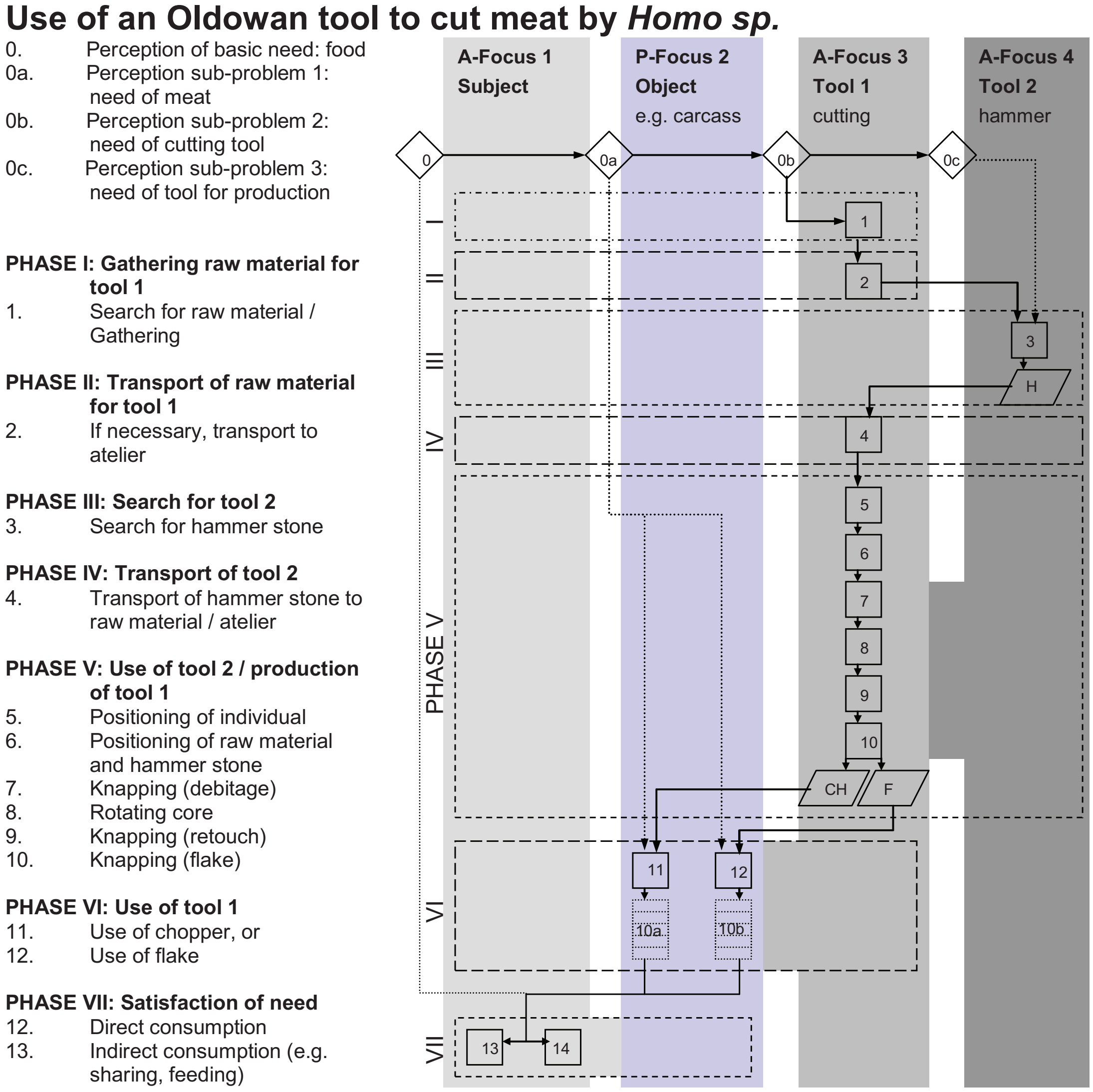


Fig. 20 Cognigram of the cracking of *Panda oleosa* nuts among chimpanzees (*Pan troglodytes*): Graph resulting from the description of the action chain after Joulian (1996), with the subdivision of the comprehensive Phase I into four individual phases and complemented by the conscious perception of needs and problems (0–0c) preceding the actions. In addition to the criteria usually illustrated, the four subphases also integrate the subject's changing foci of attention during the action.

The definition of phases in Joulian (1996) is inconsistent. In order to achieve uniform results, it is suggested to define phases or process sections as the combination of closely related individual actions that lead to an intermediate result. A phase cannot be interrupted and then resumed at the same place some time later, but has to be started over from the beginning of the sequence. The following always constitute different phases:

- the search for raw material or a tool and an object to be acted *upon,* even if they are in the immediate vicinity of the subsequent action in which they are employed;

- the manufacture of a tool;
- the transport of raw material, a tool or an object to be acted *upon,* if they are not in the immediate vicinity of the subsequent action in which they are employed;
- the use of a tool;
- the satisfaction of a need.



Use of an Oldowan tool to cut meat by *Homo sp.*

0. Perception of basic need: food
0a. Perception sub-problem 1: need of meat
0b. Perception sub-problem 2: need of cutting tool
0c. Perception sub-problem 3: need of tool for production

PHASE I: Gathering raw material for tool 1
1. Search for raw material / Gathering

PHASE II: Transport of raw material for tool 1
2. If necessary, transport to atelier

PHASE III: Search for tool 2
3. Search for hammer stone

PHASE IV: Transport of tool 2
4. Transport of hammer stone to raw material / atelier

PHASE V: Use of tool 2 / production of tool 1
5. Positioning of individual
6. Positioning of raw material and hammer stone
7. Knapping (debitage)
8. Rotating core
9. Knapping (retouch)
10. Knapping (flake)

PHASE VI: Use of tool 1
11. Use of chopper, or
12. Use of flake

PHASE VII: Satisfaction of need
12. Direct consumption
13. Indirect consumption (e.g. sharing, feeding)

Fig. 21 Cognigram of the manufacture and use of Oldowan choppers: Graph resulting from the description of the action chain after Joulian (1996), with the subdivision of the comprehensive Phase I into four individual phases and complemented by the conscious perception of needs and problems (0–0c) preceding the actions. In addition to the criteria usually illustrated, the four subphases also integrate the subject's changing foci of attention during the action.

Thus, the description of the nut-cracking process results in the subdivision of Joulian's comprehensive Phase I (cf. fig. 19) into four individual phases (fig. 20). The transport of the nuts to the anvil does not have to be attributed its own individual phase, since they are in immediate vicinity to each other. In the manufacture of a chopper (fig. 21), Joulian's comprehensive Phase I can be split into two to four phases, depending on the organization of the action. In this simple example, the production site is assumed as a given location, predestined, for example, by the presence of a cadaver to be butchered. If the raw material and the hammer are transported there separately, the action requires four phases; if the raw material is transported together with the hammer, the action only requires three phases. If the raw material as well as the hammer were to be found in the immediate vicinity, only two phases would be sufficient to complete the action.

At the same time, the different actions were split according to their level of problem and color-coded to represent different foci of attention, so that the cognigram – as opposed to the *chaîne opératoire* – allows a direct reading of which problem level or focus of attention is active during any given action phase. This mode of illustration demonstrates that nut-cracking, as described by Joulian, requires four different foci of attention: the subject, the nut as object, the anvil as specific location (that can incidentally be used or changed as an object), and the hammer tool. The flaking of a chopper also requires four foci: the subject, the object to be manipulated by the tool (such as, e.g., a cadaver), the tool (chopper and/or debitage), and another tool, the hammer, to produce the chopper and the debitage. Thus, the number of foci by itself does not indicate any difference between these two action chains.

The difference between primary and secondary tool use lies in the number of active and passive foci of attention (A and/or P focus) and in the relationships of the foci that build on each other (see fig. 22). During nut-cracking, only two foci are active, i.e., have to be controlled by the subject with respect to their modifying effect: the subject itself and the hammer as a tool. While anvil and nut are allocated their own foci of attention, they remain passive; none of these action elements effect any change (nut) or the change cannot be controlled by the subject (anvil). While the hammer affects the nut in a controlled manner, the anvil remains unaffected. By contrast, the production and use of a chopper requires three active foci of attention: the subject, the chopper as tool 1, and the percussion stone to manufacture the chopper as tool 2. This simple example already demonstrates the difference between a completely unmodified, used-as-found tool, such as the hammer or percussion stone, and a modified, manufactured tool, such as a chopper, a flake, or a twig probe. While the probe is affected and modified by the subject, who has to break off the twig, defoliate and debark it, the hammer tool does not require any further action or additional focus in its conception.

In contrast to the probe, choppers or flakes are produced with the help of a second tool, a percussion stone. While in the case of the hammer only one focus has a controlled modifying effect on another (hammer on nut; fig. 20), in the case of the probe there are already two foci that effect modifying changes, one after the other (subject on probe, probe on insect nest). In the manufacture of flaked stone implements, there are also two different foci of attention within the chain of effects: percussion stone on stone, stone tool on object, such as food, for example. The difference with regard to the probe is that here three active foci of attention have to be controlled within a phase – the percussion stone, the stone to be modified, and the subject.

Generally, the breakdown and illustration of a thought and action chain in a cognigram depicting multiple foci of attention can be subsumed as follows (fig. 22): The mental starting point is a basic need of the subject, which should be satisfied at the end of the action chain. A basic need that cannot be satisfied by the subject's action on itself leads to the perception of one or more subproblems (illustrated as the basic need as diamonds), which each opens a focus of attention, such as, e.g., an object needed for the solution, like species-specific food, a tool, or a subordinate need of the subject. The action taken following the basic need and the perceived subproblem is subdivided into minute units, so-called action steps. The first step in an action chain (illustrated as a square containing the number of the step) proceeds from the perception of a problem and takes place within the focus of attention opened by this perception. Further steps in the action chain are assigned to their main focus: the manufacture of a tool to the tool focus, the modification of an object with this tool to the object focus, and so on.

The sequence of the thought and action process, as well as potential feedback, are marked by solid arrows, the resumed use of a tool already manifest in an earlier part of the action chain (illustrated as a rhomboid) is represented by a dashed arrow. The sequence of further problem perceptions outside the main action chain is illustrated as a dotted arrow: On returning to an already open focus of attention, the respective problem perception is reactivated and subsequently initiates the further action steps within this focus.

The foci of attention underly the thought and action chain as solid-colored bars. Which foci of attention are open at any given time in the action chain can be derived from the delimitation of the action phases. These phases have to be understood as the combination of closely related action steps leading to an intermediate result that cannot be disrupted and then resumed at the same point the disruption occurred at a later time: Resumption has to take place at the start of the phase. They are represented by dashed rectangles that only comprise the open foci for that respective phase. Subject and tool foci, that is, A-foci with effects that have to be controlled actively, can overlap other foci by specifically influencing them physically or psychologically. This phenomenon is illustrated by filling in the gap between the foci – with the color of the active focus in case of physical interference or with the hatched color of the active focus in case of psychological influence.

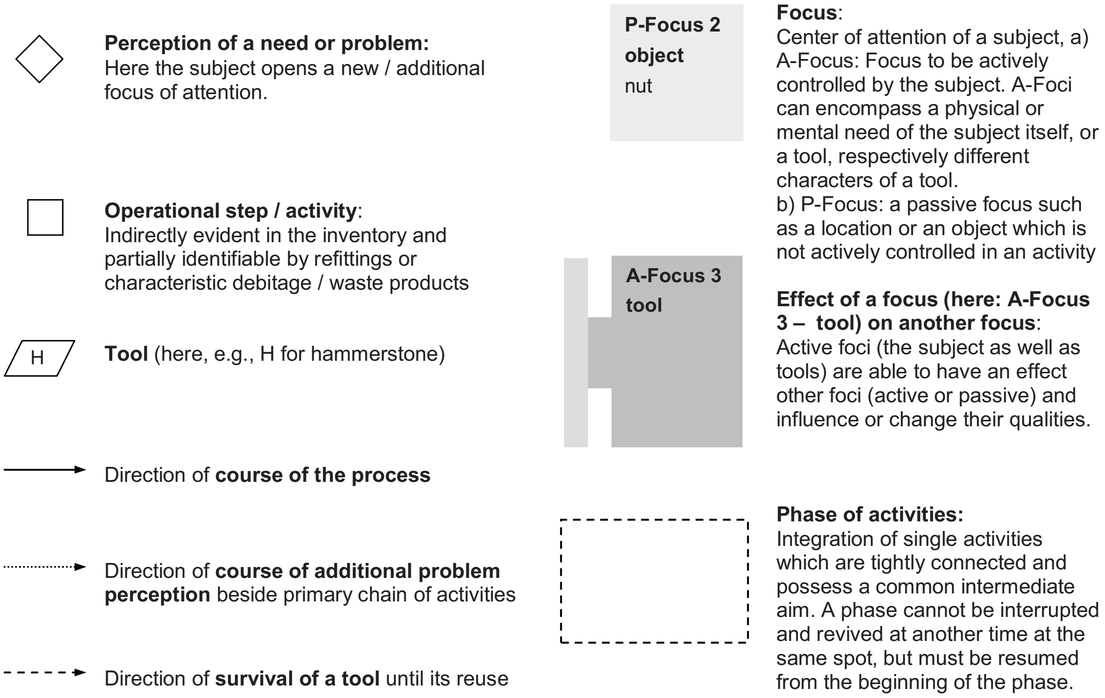


Fig. 22 Key to the cognigrams.

Since in the following I will break down different examples of tool use in animals, and later in humans, using the cognigrams introduced above, I would like to start with a closer examination of the emergence of the cognitive foundations for tool use and the development of the problem-solution-distance.

17 Animal Tool Behavior

From snails to humans – very different species of animals use tools. Amongst the vertebrates, only reptiles and amphibians have so far not been observed to exhibit tool behavior. Tool behavior among animals can serve different purposes, such as the acquisition of food, brood or offspring care, it can occur within threatening or intimidating behavior, as well as in defense or protection mechanisms. With the help of tools, animals can disguise themselves, take care of personal hygiene in the widest sense of the word, increase their personal well-being, and stimulate themselves. Objects are used to stabilize and straighten up their bodies, or to increase the personal range of action. Whether objects are actually used as decorative tools, such as in the antler "decorations" among several deer species or the drapings among the great apes, still remains unclear. Tool behavior occurs during solitary as well as social play and also includes the use of living "objects," just as in tool use as social stimulus (to buffer aggressive behavior, to initiate contact, or to attract attention). The following simplified characterizations of different animal groups mainly document behaviors observed in animals living in the wild; a complete, tabulated list of the data they are based upon can be found in the appendix.

Invertebrates

Observations of tool use among molluscs are few and far between. Only two species of marine top snails, *Tegula brunnea* and *Tegula funebralis,* the carrier snails *Xenophora conchyliophora* and *Xenophora pallidu,* as well as two octopus species, *Octopus vulgaris* and *Octopus disgusti,* exhibit any indicators. The behavior of the carrier snails falls into the grey area between nest-building and tool use: they cement stones and shells to their shells with the help of secretions from a gland in their foot, in order to disguise themselves and to gain additional stability (Beck 1980; Becker 1993: 17–18). Top snails, by contrast, use stones they pick up and position with their soles as counterweights to straighten themselves up (Weldon and Hoffmann 1975). Here, tool behavior is directly related to the subject itself, as is also the case among *Octopus disgusti,* who uses shells as artificial *opercula* (lids) for snail shells it inhabits (Berry in Thorpe 1963 in Beck 1980). Only the Common Octopus possibly uses a tool in the acquisition of food: already Pliny mentions that the animal uses a stone as a wedge to keep the valves of larger shells open while it eats. Confirmation of this behavior comes from only one incidental observation by Jeanette Powers in 1857 (Becker 1993: 18).

There are more reports on tool use among crustaceans, although many of the behaviors would rather have to be characterized as tool application, similar to the carrier snails and in anticipation of later executions. Hermit crabs of the genus *Pagurus* and *Dardanus* choose different snail shells matching their own size during their lifetime and carry them around with them (Beck 1980; Becker 1993). Crabs of the genera *Dromia, Stenorhynchus,* and *Dardanus* cement shells and sea anemones to their own shells in order to disguise or protect themselves from natural enemies. *Melia tessellata* not only uses the poisonous sea anemones passively, but also waves them around in defense and to attract prey (Beck 1980: 18). This example may serve as the first indicator that not only inanimate objects, but also living organisms and even members of the same species can be used as tools for various purposes.

Several groups of insects – hymenoptera, assassin bugs, and ants – regularly display tool use, whereby generally the form of behavior and its respective context is limited to one stage of their lives. The larvae of the antlions *Myrmeleon formicularis* and *Euroleon nostras* and of the snipe flies *Lampromyia* and *Vermileo* throw sand at their prey (Becker 1993: 24–27), the larvae of the green lacewing *Chrysopa slossonae* feed on certain species of aphids and use the wax deposits from their carapace to disguise and protect themselves from the ants tending the aphids (Beck 1980: 14–15). Disguises are also employed by the assassin bug *Salyavata variegata*, which use material from termite nests as camouflage and attracts further termites with the carapace of its first victim (Becker 1993: 23–24). The digger wasps *Ammophila* and *Sphex* secure the entrances to their subterranean nests by compacting the sediment in place with stones, clumps of earth, pieces of wood or bark, and seeds; some individuals seem to go so far as to check the thus achieved level of density with probes (Beck 1980; Becker 1993: 28–29). Among ants various forms of tool behavior were observed. Weaver ants of the genera *Oecophylla* and *Campanotus* use their own larvae and the sticky secretions they produce to glue leaves together as the cover of their nests. Several species of the myrmicine ants *Aphaenogaster* and *Pogonomyrmex* use pieces of leaves, wood, mud and sand as sponges, making the transport of liquids of up to ten times more effective (Beck 1980: 16).

Fishes

Owing to their natural environment, the tool spectrum among fishes is limited. Only archerfishes (*Toxotes*), gouramis (*Colisa, trichogaster*), and triggerfishes (*Balistes fuscus*) has thus far been observed using tools. Archerfishes and gouramis shoot down flying insects with a stream or droplets of water and then collect their prey from the surface. While adult *Toxotes* can target insects up to a distance of 1.5 m, the range of the gouramis is limited to several centimeters (Beck 1980: 20–21; Becker 1993: 33–36). The Rippled Triggerfish squirts water from its mouth underwater to flip over sea urchins and expose and open their less spiny undersides (Fricke 1972 in Becker 1993: 37). In addition to spitting water droplets while hunting, the honey gourami (*Colisa chuna*) exhibits a similar behavior in parental care in order to find loose eggs and reattach them to the foam nest (Becker 1993: 36). While both Beck (1980) and Becker (1993) have no problems to classify the use of water by fishes as tool behavior, I have my doubts as to whether this can be considered true tool use behavior. Water to fishes is as air to land-dwelling animals – their natural surrounding element; a comparable behavior would be a child blowing off a fly. In this case, water is not a detached or detachable object, but only appears as such once the stream of droplets clears the surface. Thus, it is not the manipulation of a tool that achieves the effect, but a variation of a common bodily function. Correspondingly, the behavior among African and Asian elephants to clean themselves or the floor of their cage with pressurized air from their trunks, which is cited as tool behavior by Chevalier-Skolnikoff and Liska (1993: 213), remains debatable in my opinion.

Birds

Birds, on the other hand, exhibit truly varied tool behavior (cf. Boswall 1977; Beck 1980: 21–31; Becker 1993: 38–66; Lefebvre et al. 2002: 952–54), within their natural environment as well as in captivity and under various circumstances. Different species use bait to catch fish (see Chapter 18; Lefebvre et al. 2002: 948; Becker 1993: 59–62; Beck 1980: 28–29), or throw objects at food to open it or at other animals to chase them away and thus be able to loot their clutch of eggs (van Lawick-Goodall and van Lawick-Goodall 1966; Beck 1980: 23–25; Becker 1993: 40–44, 62–63). Birds use stones as hammers (Beck 1980: 24; Becker 1993: 39–40) and probe for insects with different tools, such as the widely known woodpecker cinches (*Camarhyncus pallidus* or *Cactospiza pallida*) of the Galapagos Islands and related species (Beck 1980: 25–26; Becker 1993: 52–55; Lefebvre et al. 2002: 953). The New Caledonian Crow (*Corvus moneduloides*) is known to employ two types of probes that differ markedly in their raw material as well as their manufacture, and which each can occur in several sub-varieties (Hunt 1996; 2000a; 2000b; Hunt and Gray 2003; 2004).

Apart from subsistence purposes, tools are also used in parental care; the Brewer's blackbird (*Euphagus cyanocephalus*) dips his prey in water in order to provide his young with a drink (Koenig 1985 in Lefebvre et al. 2002: 953), the white stork (*Ciconia ciconia*) does the same with moss (Rekasi 1980 in Lefebvre et al. 2002: 952). Used in personal hygiene and/or stimulation is a behavior widely spread among starlings and sparrows known as anting, where the birds usually rub ants on their feathers, although they will also use beetles, onions, cigarette butts, mothballs, and beer (Beck 1980: 30–31, 136–38); however, Becker does not consider this behavior as distinct tool use (Becker 1993: 14). While the construction of the elaborate and often highly decorated bowers by bowerbirds by definition does not count as tool behavior, tools are sometimes used during their construction. Different species of bowerbirds paint or plaster the insides of their bowers with a mixture of saliva and pigment or berries, blossoms, bark, or dried grass used as cement. During this process, a bundle of fibers or dried grass keeps the bird's beak slightly open, keeps the mixture from issuing at the tip of the beak, and at the same time soaks up excessive mixture (Beck 1980: 22; Becker 1993: 57–59).

Mammals (other than Primates)

Between the different groups of mammals, frequency and form of tool behavior differ enormously. The spectrum of tool functions increases: besides subsistence and hygiene, intra- and inter-species social aspects gain importance in defense, overawing, and play. Locomotion is another field of functions that gains importance. While among the animal groups surveyed so far – except for a few birds – each species usually exhibits tool behavior only in one area of activity, several mammal species not only use different tools, such as in subsistence, but also use different tools in different contexts. Sea otters (*Enhydra lutris*), for example, use stones within a subsistence context, but also kelp to keep them afloat.

Other than throwing polar bears, other bear species using different tools, egg-opening mungos, a great panda cleaning itself, and a dog practicing dental care (Beck 1980: 38–41; Becker 1993: 74–76), sea otters are the only predators/carnivores that have been observed using tools (Hall and Schaller 1964; Beck 1980: 41–44; Becker 1993: 70–74). Californian groups regularly open shells while swimming on their back by balancing them on their chest and cracking them open with a stone, but they also use stone hammers to dislodge abalone shells from the bottom of the sea and keep themselves afloat for short naps in the water by anchoring themselves to strands of kelp. Amongst rodents (Beck 1980: 31–32; Becker 1993: 66–68) and ungulates (Beck 1980: 36–38; Becker 1993: 77–78) tool use is rare. Tool use among whales has only recently been observed in animals living in the wild (Taylor and Saayman 1973 in Beck 1980: 166; Krützen et al. 2005; Mason 2005; see Chapter 18). Rough-toothed dolphins (*Steno bredanensis*) seem to transpose a behavior also known in orcas (*Orcinus orca;* Heise et al. 2003), the throwing around of prey until it are dead and easier to eat, into a play context as well, where the living “toy” actually often survives.

Next to primates, elephants exhibit the widest range of tool behavior – to threaten, in personal hygiene, or to expand their range of action (Chevalier-Skolnikoff and Liska 1993). Whether the covering of dead members of the same species, other animals, and humans can be classified as tool use, as Beck asserts (1980: 34), or has to be viewed in the context of nest-building or other constructions, has to remain an open question in the light of the behavior's uncertain function. If the objects used in the covering are truly tools, who or what do they physically or psychologically affect? The acting subject, the object to be covered, or something completely different?

New World Monkeys

Primates exhibit the most extensive tool behavior of all orders within the animal kingdom, but only some primate species use tools, and not all use them to the same extent. Among the New World monkeys, the isolated use of tools has been observed in different genera. Tool use among howler monkeys (*Alouatta*), woolly monkeys (*Lagothrix*), squirrel monkeys (*Saimiri*), spider monkeys (*Ateles*) and sakis (*Pithecia*) is limited to the dropping and, occasionally, throwing of branches at intruders. Capuchin monkeys of the genus *Cebus,* by contrast, exhibit a more differentiated use of tools in various contexts, in the wild as well as in experiments in captivity (*inter alia* Beck 1980: 46–51; Becker 1993: 80–84; Chevalier-Skolnikoff 1990; Parker and Gibson 1977; Westergaard 1995; Westergaard and Suomi 1995). Most of the time, the observations of these tree-dwelling animals are not systematic with regard to their tool use; thus, it has to remain open, whether it is only accidental that the method of tool manufacture is limited to mere detachment without further modification. Only in one, not further identified *Cebus* species has the manufacture of an insect probe been recorded as not only the simple detachment of the twig, but also its modification by debarking (Jay 1968 in Becker 1993); however, the method of tool production among many capuchin monkey species has not been documented adequately.

The opening of hard-shelled food with different hammers is common among several species of capuchin monkeys, and it is striking that tool and object are often the same: *Cebus albifrons* opens cumare fruit by smashing them together, *Cebus apella* uses palm nuts to open palm nuts and oysters to open oysters. In these situations, a clear differentiation between the object and tool or proto-tool status of the objects involved is not possible (Becker 1993: 81; cf. Chapter 18). While it is not unusual for animals in captivity to use stones or pieces of wood to open foodstuffs, it seems to be an unusual and maybe even non-existent trait amongst animals in the wild. While Dampier's frequently cited eye-witnessing of capuchins opening oysters with stones in 1697 does not hold up to close scrutiny of the original source (Becker 1993: 83), observations by the local population and the frequent association of stones and empty nutshells led to the assumption of the use of stones as hammers among *Cebus apella.* Ottoni and Mannu (2002) were eventually able to prove this behavior in a group of semi-wild animals. It is interesting to note the posture of the animals, which involves using their powerful tail as a stabilizing aid to their two-legged stance while swinging the hammer stone (fig. 23).

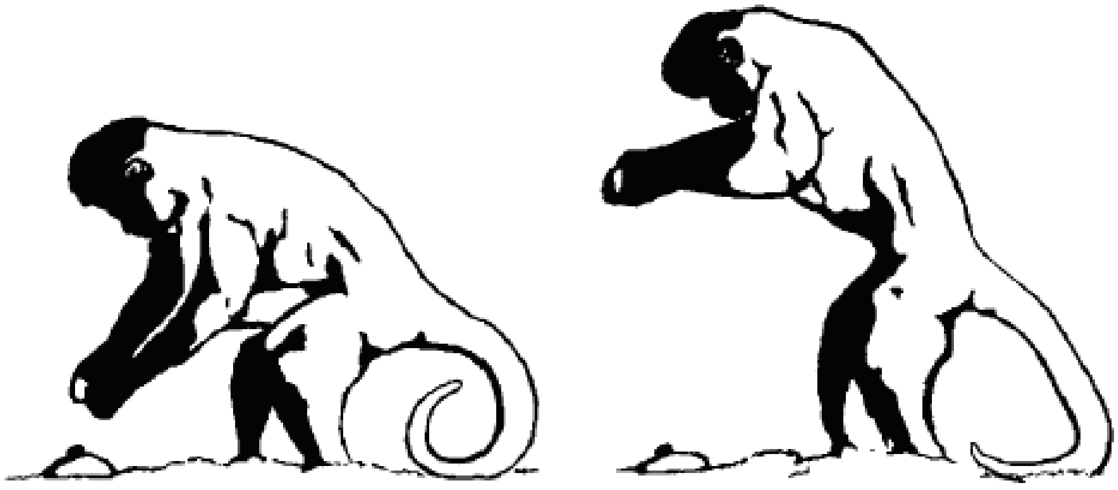


Fig. 23 Capuchin monkeys cracking open nuts with a stone hammer (from Ottoni and Mannu 2001).

Old World Monkeys

Isolated tool use in the natural environment among Old World monkeys living in Africa and Asia has been observed in colobus monkeys (*Colobus* or *Procolobus*), surilis (*Presbytis*), long-nosed monkeys (*Nasalis larvatus*), mangabeys (*Cercocebus*), guenons (*Cercopithecus*), and patas monkeys (*Erythrocebus patas;* Beck 1980: 51–53; Becker 1993: 87). In most cases, the context is overawing or intimidating behavior, where stones, sand, and branches are thrown or dropped, just as among New World monkeys. Additionally, there are reports of western red colobus monkeys (*Colobus* or *Procolobus badius*) and unspecified mangabeys widening the entrances to subterranean insect nests with sticks (Jobaert in Koortlandt and Kooij 1963 in Beck 1980: 52).

In captivity, different species of macaques (*Macaca*), which together with baboons belong to the family of *Cercopithecinae,* demonstrate different forms of tool behavior in subsistence and play contexts, both spontaneous and within experiments, while the same animals living in the wild mainly exhibit the purposeful throwing, rolling, or dropping of objects as part of overawing or threatening behavior (Beck 1980: 53–56; Becker 1993: 87–88). Crab-eating macaques (*Macaca fascicularis*), which transport stones over a distance of up to 75 m in order to crack open oysters, and barbary macaques (*Macaca sylvana*) seem to be exceptions to this rule; the latter even demonstrate three different types of tool behavior: the crushing of scorpions with stones (Beck 1980: 55), the throwing of roof tiles at pursuing humans (*ibid.*: 53), and the use of young animals as social buffer when approaching an aggressive male in an antagonistic situation (*ibid.*: 56). Besides the washing of food (potatoes, cereals), which is not defined as tool behavior, Japanese macaques (*Macaca fuscata*) develop striking play behavior. Eaton (1972) reports borderline tool behavior, where big snowballs were rolled and then used as elevated seats, among a group of captive but mostly uninfluenced living animals in an outdoor enclosure in Oregon. Huffman and Quiatt (1986) cite no less than eight different types of stone-handling observed among wild groups that were, however, provided with additional food.

The family of *Papionini,* which includes baboons (*Papio*), geladas (*Theropithecus*), mandrills and drills, uses the most varied selection of tools among primates, only to be surpassed by humans (Beck 1980: 57–67; Becker 1993: 85–87). While tool behavior amongst mandrills (*Mandrillus sphinx*) and drills (*Mandrillus leucophaeus*) has thus far only been observed in captivity, the different species of baboons and geladas exhibit this behavior also in their natural environment. In the wild, chacma (or cape) baboons (*Papio ursinus*), which when caged and limited in their range use objects as probes, rods, lines, levers, ladders, and digging sticks, mainly employ stones to break open the fruit of the Baobab tree or to throw or roll them at intruders. A unique observation reports a male specimen that took a palm frond and placed it over a tree stump on which it than sat and enjoyed the sun (Beck 1980: 67; Becker 1993: 85–86). Yellow baboons (*Papio cynocephalus*) are only known to probe subterranean termite nests in the wild, while sacred baboons (*Papio hamadryas*) use tools for defensive as well as offensive purposes: they are reported to purposefully throw sand or dirt into the eyes of their non-human enemies, and they also roll down stones from elevated points, as for example in altercations with competing groups of geladas (Beck 1980: 57–59). Additionally, tool behavior among baboons is often observed in a social context. Lower-ranking Sacred baboons, as well as olive baboons (*Papio anubis*) and Guinea baboons (*Papio papio*), use young animals as pacifying buffers in situations where they are scared by stronger, aggressive male animals. An olive baboon was also observed to probe with a stick in the mud for small stones, which he then cleaned and sorted for further use as a digestive aid (Oyen 1978 in Beck 1980: 66). Throwing and dropping stones among this species is not only employed against intruders, but also possibly serves in the hunt for goats, if reports by the local human population are correct (Pickford 1975 in Becker 1993: 87). Olive baboons are also the only species of *Papionini* that practice tool use in personal hygiene, as evidenced by the stones and nibbled-off corn cobs they use to clean their faces of sticky substances (van Lawick-Goodall et al. 1973). As it is, they are – next to the great apes – the most versatile tool users amongst the primates. However, except for the breaking off of a twig to use as a probe by one Yellow baboon and the digging up of stones to roll at intruders by Chacma baboons, no tool manufacture amongst *Papioninis* in the wild could be documented thus far.

Apes

White-handed gibbons (*Hylobates lar*) are the only species of small apes that have thus far been reported to use tools. In the wild, they only exhibit the breaking-off and throwing or dropping of branches at intruders or human observers, a behavior they also employ in intra-species conflicts (Beck 1980: 67–68; Becker 1993: 88–89).

Although tool behavior amongst the great apes have already been discussed elsewhere (cf. Chapters 3 and 14), I would like to summarize the most important points again in order to facilitate comparison with other species. While studies of zoo animals (Boysen et al. 1999; Jordan 1982; Parker et al. 1999) verified versatile tool use not only amongst chimpanzees (*Pan troglodytes*) and orangutans (*Pongo pygmaeus*), but also for gorillas (*Gorilla gorilla* and *Gorilla beringei*) and bonobos (*Pan paniscus*), long-term observations only recently succeeded in documenting tool behavior amongst other species than chimpanzees in the wild (Breuer et al. 2005; Fox et al. 1999; Fox and bin'Muhammad 2002; Hohmann and Fruth 2003; Ingmanson 1996; Parnell and Buchanan-Smith 2001; van Schaik et al 1996; van Schaik and Knott 2001; van Schaik et al. 2003).

Orangutans have the distinction of using a wide variety of tools to facilitate movement, and some of these behaviors are clearly group-specific (van Schaik et al. 2003). The groups of Agusan and Ketambe on Sumatra use leaf padding on the soles of their feet and hands to climb prickly durian trees and to handle their equally prickly fruit. Hooked branches are used to reach otherwise inaccessible branches (Fox and bin'Muhammad 2002). Semi-wild animals at a reintroduction station were observed to use tree trunks and boats to float across rivers. A male individual held on to the boat even during other activities, such as the search for food, to be able to use it again at a later time. The animals constructed bridges from smaller tree trunks to cross creeks and also used the trunks as ladders by balancing them or leaning them against something (Galdikas 1982).

Compared to other apes, orangutans also seem to employ tools as psychological aids or to let off steam (Beck 1980: 70–71, 75). When approaching members of the same species, in the presence of humans, or during play, the animals often drape plants or plant parts around their heads and shoulders. The covering of the head, neck, and/or back has also been observed repeatedly as a mean of physical comfort: to shield against sun or rain, against insects, and –in captivity – as a cover during the night (Beck 1980: 75–76). In intimidating behavior, branches are usually thrown or dropped from trees (Beck 1980: 69–70; Becker 1993: 91–92), and every now and then leaves are used to wipe the mouth or to clean feces from a youngster's fur (Beck 1980: 75; Becker 1993: 91). Orangutans use branches and twigs to explore unknown or scary objects (Becker 1993: 93), scratch themselves in hard-to-reach places (Beck 1980: 72; Becker 1993: 92–93), and chase away flying insects (Becker 1980: 71; Becker 1993: 92). As stimulation, objects are rubbed against the genitalia (Beck 1980: 75). Tool use and tool manufacture in the subsistence context is varied and often directly affects the food, such as in the use of different probes to acquire ants, termites, stingerless bees and their honey, or the seeds of the Neesia fruit (Fox et al. 1999; see Chapter 18). Sometimes, however, tools are used indirectly, such as the leaf paddings cited above.

For the longest time, reports on tool use amongst gorillas usually did not differentiate between the different varieties of gorilla (cf. Beck 1980: 76–79; Becker 1993: 93–95), since it was assumed that a division existed only on a subspecies level. Recently, however, mtDNA analyses (Jensen-Seaman et al. 2004) have allowed to distinguish between eastern gorillas, which include mountain gorillas (*Gorilla beringei beringei*) and eastern lowland gorillas (*Gorilla beringei graueri*), and western gorillas, which include western lowland gorillas (*Gorilla gorilla gorilla*), and recent reports now clearly identify these species (Breuer et al. 2005; Nakamichi 1998; 1999; Parnell and Buchanan-Smith 2001). In the following, I will refer to exact specification if applicable and otherwise just talk about gorillas in general. As opposed to the often voiced assumption that these two species of central African great apes do hardly exhibit tool behavior, indications of tool use amongst wild animals could be found even in older literature. However, tool use in the context of food acquisition, which is especially complex amongst mountain gorillas, is thus far lacking (Byrne 1996; 1999).

As all the other great apes, gorillas use objects that they purposefully or randomly throw or drop to increase the effect of their intimidating or overawing behavior towards humans or members of the same species. Within the same context, they brandish branches or beat them with bamboo shoots (Beck 1980: 76–77; Becker 1993: 94–95). Western lowland gorillas demonstrate a particular behavior in open, marshy glades, which employs water as a proto-tool in ten different variants (fig. 24). Mainly silverbacks, but always male individuals, beat the water into fountains with intimidating intent, also more rarely in play. This behavior is usually directed at other male animals or other species, though rarely also at female gorillas (Parnell and Buchanan-Smith 2001). Another use of water, this time as a true tool, was observed by Beck (1980: 78) among male individuals in the zoo, who held water in their fists in order to increase the volume of their chest beating.

Fig. 24 Male western lowland gorilla (*Gorilla gorilla gorilla*) during overawing behavior supported by splashing fountains of water (from Parnell and Buchanan-Smith 2001).

Whether gorillas indeed use sticks to reach otherwise inaccessible fruit has to remain open, since Phillips later doubted her own observations on the subject (Beck 1980: 77). A unique occurrence is the picking of a flower by an old male gorilla, who used it to tickle a young animal (Becker 1993: 94). Adult western lowland gorillas using different tools to clean not themselves but young animals is a peculiar behavior so far only observed among zoo animals (Fontaine et al. 1995; cf. Chapters 18 and 19). Both wild animals and those held in captivity pile up plant matter on wet or humid ground to create a dry sitting place – a borderline case of tool behavior.

Real tool behavior is documented for the use of sticks by two female western lowland gorillas. One animal used a stick to gauge the depth of water and as support while crossing a swamp (fig. 25). The other animal used the stick she had broken off first to keep herself from slipping into the water while fishing for water plants in a swamp, and – after she had satisfied her hunger – to cross the same swamp on dry foot (see Chapter 18, figs. 31–32; Breuer et al. 2005).

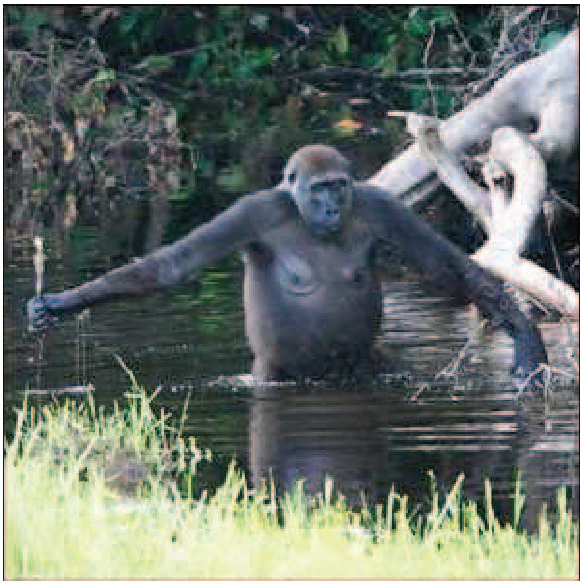


Fig. 25 Female western lowland gorilla (*Gorilla gorilla gorilla*) crossing a swamp with the help of a stick to gauge the depth of the water and as support (from Breuer et al. 2005).

While Beck (1980) and Becker (1993) already regarded bonobos as a separate species, but did not consider their tool behavior separate from chimpanzees owing to a relative sparseness of indicators, and Frans de Waal (1998) in his overview of dwarf chimpanzees also did not mention tool behavior, our knowledge in this field has increased enormously during the last years. Jordan's study (1982) provides a good overview of tool use in captivity, and Ingmanson (1996) as well as Hohmann and Fruth (2003) give an insight into the varied use of tools in the wild. It is remarkable that tool use in a subsistence context among bonobos is markedly reduced in comparison to chimpanzees. Thus far, only the use of moss as sponges has been documented (Hohmann and Fruth 2003); possible digging sticks, which were found with dirt clinging to both ends, are assumed to have been used in the search for termites or mushrooms (Kano 1979 in Becker 1993: 110).

Bonobos often use objects as visual or acoustic signals in various social contexts. Besides the purposeful throwing of objects, branches are dragged through the underbrush while running to reinforce threatening or overawing behavior. This noisy branch-drag is also frequently used in decampment situations when a group moves on to a different place. The acoustic stimulus created through stripping branches of leaves by hand is employed to overawe as well as in play. Similar behavior – although rather with a visual effect – is reported from female individuals that pick leaves apart by hand in an attempt to appear attractive to specific male animals. Juveniles of both sexes and adult females pick small leaves and hold them with their mouth while contemplating other members of the group (Hohmann and Fruth 2003). Jordan (1982) reports the repeated generation of acoustic stimuli with the help of tools among zoo animals.

Tools in the conventional sense are used by bonobos to increase their personal comfort and well-being. They scratch themselves with twigs, use leaves to clean fur of fecal matter, employ twigs as toothpicks, use leafy branches to chase away insects (Ingmanson 1996; Hohmann and Fruth 2003) or to protect themselves from rain (Kano 1982; Ingmanson 1996; Hohmann and Fruth 2003). While in their sleeping nests, bonobos occasionally cover their belly with leafs and twigs, and they bend down branches without snapping them to use as seats (Hohmann and Fruth 2003); this behavior has to be considered borderline tool use.

Play behavior is extremely pronounced among bonobos. Besides the acoustic signals mentioned above (leaf-strip and leaf-clip), there are solitary as well as social games that integrate inanimate objects and other animals. Besides solitary play that resembles the stone-handling amongst Japanese Macaques (see above), Ingmanson (1996) describes games of tag using a stick as a signal among bonobos (see Chapter 18). The stick indicates which animal is supposed to be tagged and also serves as a more general signal: if it is dropped, the game is interrupted. Additionally, bonobos have been observed covering a bushbuck with twigs (Becker 1993: 110) and using guenons and colobus monkeys as living toys (Hohmann and Fruth 2003), without harming the respective animals.

Besides humans, chimpanzees (*Pan troglodytes*) are the most versatile tool users. Even in wild populations, they regularly use tools manufactured in different ways (Beck 1980: 79–105; Goodall 1986; McGrew 1992; Becker 1993: 95–109; Whiten et al. 1999; 2001), notably to supplement their normal food spectrum with various insects, honey and other liquids, marrow from long bones, algae and hard-shelled nuts, and to collect tasty remains from fruit shells and peelings or the skulls of animals preyed upon. They use tools to dig, lever, crack open, probe, explore, soak up, extract, enlarge, bash, dab, clean, impress and threat, fetch, protect, stimulate, pad, fan, play, and fish. While the subsistence aspect certainly takes precedence, tool behavior in a play context is also frequent and particularly repeats and anticipates behaviors known from other contexts.

While different forms of tool behavior relating to personal hygiene and even the inspection and cleaning of wounds (*inter alia* Nishida and Hiraiwa 1982; Whiten et al. 2001) have also been observed among animals living in the wild, altruistic care for other members of the group by means of tool use is restricted to captive animals. In the Delta Regional Primate Research Center, McGrew and Tutin (1972; 1973 in Beck 1980: 91) were able to repeatedly observe a female individual cleaning the teeth of a male juvenile in second dentition with twigs and removing a loose deciduous molar. For locomotive purposes, chimpanzees in the wild have only been observed to reach for high-hanging branches with the help of other branches and to use short, smooth branches wedged between their toes to pad themselves when climbing thorny kapok trees (Alp 1997; Whiten at al. 1999; 2001).

Other than its group-specific occurrence, tool behavior among chimpanzees is characterized by its great flexibility. While the same tool types may be used under varying circumstances, similar circumstances may lead to the employ of different forms of tools or tools manufactured from different raw materials. In experiments, Whiten et al. (2005) were able to show that chimpanzees are able to recognize different solutions to a problem when observed in members of the same species, but that they typically prefer the solution they first learned themselves.

Additionally, chimpanzees are the only species, besides humans, among which the sequential use of different tools in the accomplishment of a *single* purpose has been recorded. While mountain gorillas display complex action sequences in dealing with various vegetable foodstuffs (Byrne 1999), and there are indicators – not yet bolstered by hard data – for sequential tool behavior among orangutans (Fox et al. 1999), this mode of behavior has been repeatedly observed in *Pan troglodytes*. Sanz et al. (2004) describe the use of two different sets of tools in the hunt for termites living underground or in mounds. Brewer and McGrew (1990) even report the sequential use of four different tools to open a bees' nest and extract the honey (see Chapter 18). However, in the latter case it has to remain open whether the animal anticipated the need for the full set of tools before the action, or whether the need for each tool was perceived individually *ad hoc* when the one previously employed did not lead to the required result.

Another extraordinary observation was made by Frans Plooij (1978) in Gombe. While hunting for bushpigs, a male chimpanzee threw a stone into the herd, causing them to scatter, so that the previously protected young animal in their midst could be captured. While the aimed throwing of objects at animals from other species has occasionally been mentioned (Beck 1980: 82; Becker 1993: 97), chimpanzees do not use this behavior regularly or even in a planned manner in hunting; this behavior occurred spontaneously within a given situation and did not serve to kill the prey. However, the decided killing with projectiles only constitutes a variation of this behavior, mainly by shifting the goal of the action – an exaptation of behavior (cf. Vrba and Gould 1980).

Requisite Conditions

Now, which are the factors that enable or promote tool use within an animal species? To this end, van Schaik, Deaner and Merrill (1999) developed a model for primates that looks at the subsistence context. It contains several nested conditions that each limit the range of animal species that comply with these conditions: extracting food acquisition, expert manipulation of objects, intelligence, tolerant and gregarious social life, and teaching or exchange of knowledge (fig. 26). Besides fundamental capabilities, the model is also supposed to explain the frequency of tool use among a species.

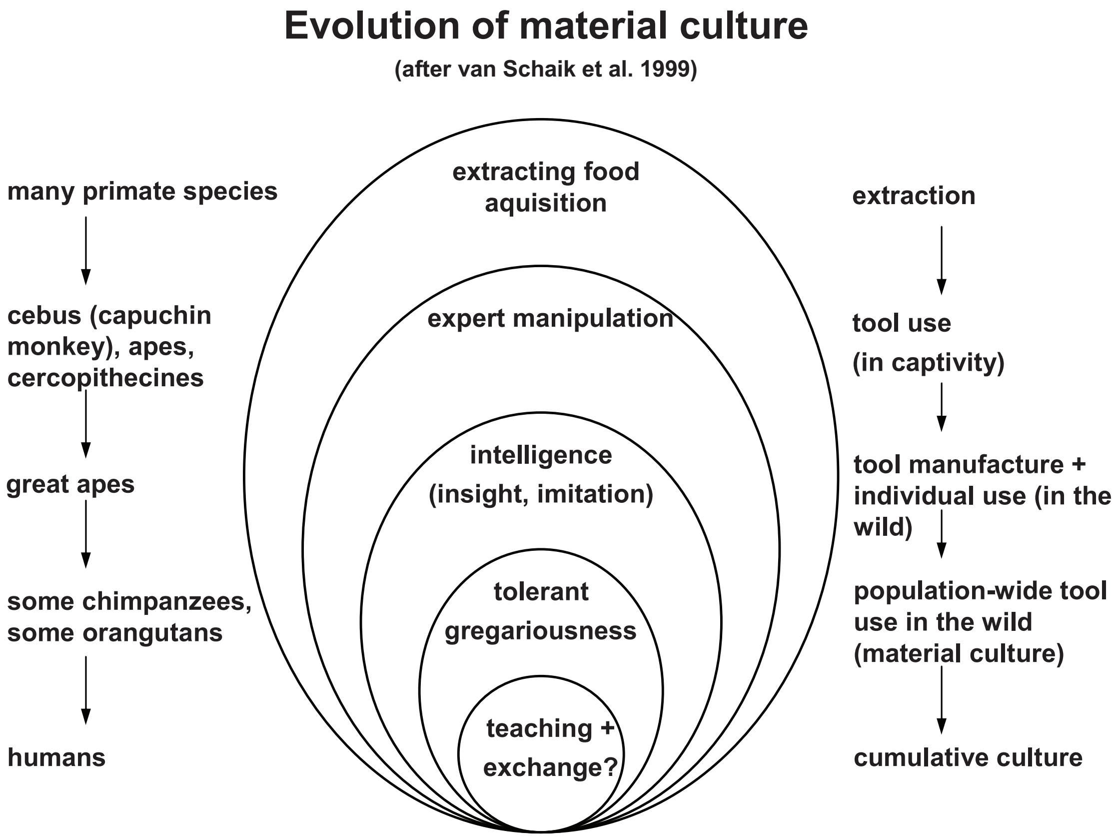


Fig. 26 The nested conditions that promote tool use within the subsistence context – from the preconditions of ecological opportunities and manipulative capabilities to cognitive and social factors that support the invention and circulation of capabilities for tool use. On the left, primate groups that comply with increasingly higher requirements; on the right, phenomena associated with the meeting of the conditions (after van Schaik et al. 1999).

Extracting food acquisition is often, but not always, accompanied by tool use: while all primate tool users within the subsistence context are expert extractors, not all extractors are expert tool users and most expert extractors do not operate in the wild (*ibid.*: 736). The physical capability to expertly handle tools is a prerequisite condition for their use, but van Schaik et al. (1999) note that only intelligence or insight and imitation enable the manufacture and individual use of tools among animals living in the wild. Additionally, regular, population-wide tool use – material culture – depends on a social life that tolerates new tool use and is gregarious. The model's final condition, which only humans meet, is teaching and the exchange of knowledge, which enable the cumulation of cultural achievements.

The model established by van Schaik et al. (1999) for the subsistence context among primates contains many important factors that also apply to tool use among other animals and within other areas of activity that are not necessarily of lower importance in the development of material culture; however, some restrictions have to be applied. In order to transfer the model onto other contexts, the term of extracting food acquisition needs to be enlarged to incorporate the more general aspect of ecological factors (fig. 27). Ecological variables can enable opportunities of tool use as well as the necessity to use implements in their exploitation. As a rule, animals face different ecological factors than they would encounter in their natural habitat. Electric fences and metal tubing protecting trees are among the variables that motivate bonobos and chimpanzees to use stout sticks and branches as ladders, in order to climb those trees despite their protections (Beck 1980: 95–97; Gold 2002). Observations of tool use in captivity can yield important indicators of the influence of different factors on the behavior of a certain species, especially when compared to studies of animals in the wild. Spontaneous tool use in captivity – that is, not under specific experimental conditions or even trained – is not necessarily a simpler form of tool behavior.

It is obvious that the physical capabilities of handling implements determine and limit tool use within a species. Sea otters with versatile paws and elephants with trunks that can grasp objects have a definitive advantage over ungulates and whale species. But even these animals use tools, such as bottlenose dolphins (*Tursiops sp.*) that pull sponges over their noses to protect them while stirring up the sea floor in the search of food (Krützen et al. 2005) or use tile to scrape algae from their tank walls (Taylor and Saayman 1973 in Beck 1980: 166). In order to scratch otherwise unreachable spots on their backs, water buffalo (*Bubalus bubalis*) and the common eland (*Taurotragus oryx*) can tear down bits of fencing or posts and balance them between their horns. Horses (*Equus caballus*) and goats (*Capra hircus*) have been observed to use sticks or straws held with their mouths for the same purpose (Beck 1980: 36; Becker 1993: 78). An orangutan's short thumbs limits their expert manipulation of tools by hand, which is why they often use their mouths in the execution of actions requiring fine motor skills (Fox et al. 1999).

Thus, it becomes clear that obvious physical capabilities are a limiting, but by no means excluding factor, since proficiencies of secondary importance for tool use at first sight may still turn out to enable the latter in the end.

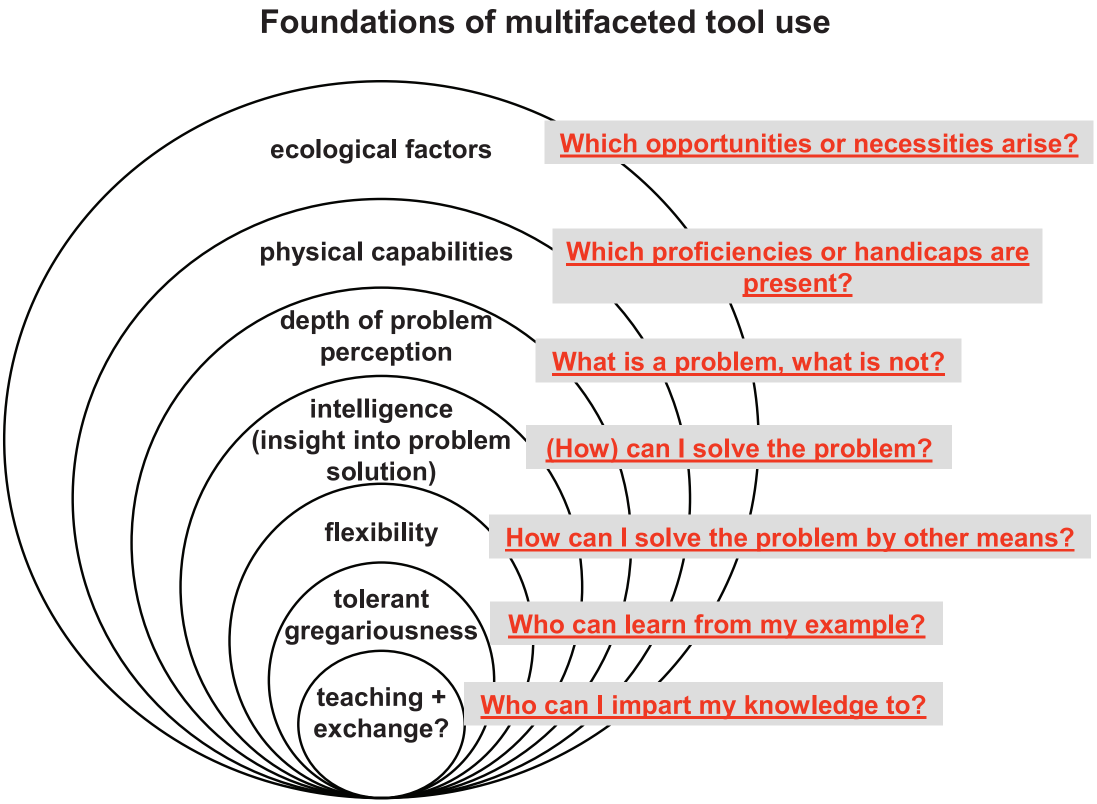


Fig. 27 Factors that promote tool use: from general ecological, through individual cognitive, to social aspects.

While the lack of physical capabilities for tool use may limit tool behavior within a species, physical characteristics, on the other hand, may render tool use redundant. Sea otters in the Aleutian Islands exhibit tool use, other than their relatives of the Californian coast, only during the juvenile and old-age stages of their lives, when their teeth are still too weak or already to abraded to open their food. Other than the Aleutian clams, which are relatively small and possess weaker shells, the clams that constitute the main food source of Californian sea otters can usually only be opened with the help of tools, even by adult animals in their prime (Hall and Schaller 1964; Jones 1951 in Beck 1980). Physical handicaps in relation to the solution of a problem promote tool use, whether in the habitual opening of hard-shelled food or the singular use of a feather by a double-crested cormorant (*Phalacrocorax auritus*). The mobility of the neck of this latter animal was probably limited by an injury, making it only possible to reach its preen gland and preening its plumage with the help of a tool (Beck 1980: 27–28; Becker 1993: 63). Consequently, the factor of expert manipulation should be extended beyond mere physical capabilities.

One factor that the model by Schaik et al. (1999) does not consider is the breadth of problem recognition – which situations are actually recognized as problems. There is no such thing as an objective problem that can be avoided. It is always subjective and dependent on the point of view of the subject; however, it is not necessarily chosen consciously. The satisfaction of a need – with or without a tool – and the satisfaction process do not have to have economic advantages, but serve to further (and increase) subjective well-being. This remains true for all functional areas of tool behavior, the emphasis on economical or psychological satisfaction varies from case to case.

Intelligence and problem comprehension vary significantly in animal tool use. Ant lions reflexively throw sand towards an external stimulus, sand knocked loose by prey crawling along the edge of the pit (comp. Chapter 18), other animals are able to learn and gain better comprehension of a problem-solution relationship. Comprehension of a problem solution in tool behavior also includes the recognition or isolation of an object from its environment and the coordination of actions and different foci of attention.

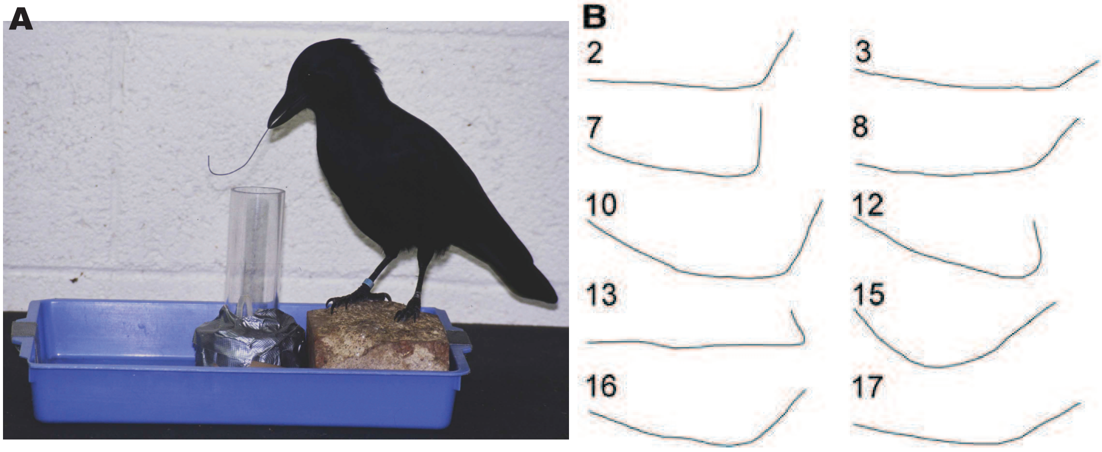


Fig. 28 The use of a spontaneously fashioned wire hook by a female New Caledonian crow (*Corvus moneduloides*) and some of the tools (from Weir et al. 2002).

Flexibility and the ability to be innovative, beside broad problem recognition and problem comprehension, are further basic cognitive abilities for versatile tool use. This aspect becomes most important during unusual situations that include a problem similar to previously solved problems; the problem is recognized and not discarded because it does not seem solvable. An excellent example of this is the spontaneous production of wire hooks by a New Caledonian crow (*Corvus moneduloides*) in an experiment in which prepared wire hooks were tested. While a male animal exclusively used the prepared wire hooks to fish food out of a pipe, a female animal bent a straight piece of wire into a hook so that she could also reach the reward (Fig. 28). In later experiments, the animal repeated this behavior multiple times; it was not previously trained to do so (Weir et al. 2002).

A number of variables in this problem are already known and recognized: Extracting food using a hook end, the circumstance that probes need to be produced and the knowledge of what a functioning probe made out of the new raw material looks like. The more elements are known, the easier innovation becomes. That is why alterations of common problem solutions can be observed more frequently than entirely new behavior, which requires the recognition of an unknown problem as well as new problem-solution relationships, new raw materials, new actions and new rewards.

The assessment whether an action is innovative and, in consequence, the determination of flexibility and innovative ability, should not be too strict or limited to new behavior. Fox et al. (1999), Kummer and Goodall (1985) and numerous archaeologists (comp. Chapter 12) believe that the innovative ability of orangutans, chimpanzees and humans remains very limited throughout large parts of their development. It is important to differentiate between individual and momentary flexibility, which is probably rarely documented by ethnographic or archaeological observations, and the establishment of innovation in a group over a longer period of time. The majority of innovations are created in short-termed and unusual situations; as soon as the situation normalizes, the subject generally returns to trusted activities and solutions. Innovations rarely lead to new problems and freedom of action.

In order for an innovation to become included in the behavioral repertoire of a group, other members of the group must recognize the problem at the same time. In addition, the solution must be reproducible with the given materials and other members of the group must be able to recognize the problem-solution relationship for themselves. Group tolerance for new tool behavior as a catalyst for the distribution of innovation can only arise if these conditions are met by making it possible for others of a group to observe and follow an action example. Teaching and exchanging knowledge can also lead to an active recognition of the problem, the problem-solution relationship and can explain and illustrate the action example.

Although all the mentioned aspects interlock, they do not represent a simple evolutionary sequence against the backdrop of animal tool behavior. Different groups and species of animals possess different, simple to complex variations of individual economic, physical, cognitive and social factors on which a species-specific picture of tool use is based. A species' intelligence and flexibility can be pronounced, while problem recognition remains limited as in *Corvus moneduloides,* where the observed tool behavior is limited to a tight problem-circle – probing to extract food – in a subsistence context. Their bodily abilities do not differ from other species of birds that do not use tools, their ecological niche, like that of the finch, focuses their attention on the extraction of food from places that are not accessible without tools. One or two forms of tool behavior may occur in a species based purely on instinctive behavior as in the ant and worm lions. At the same time, intelligent animals with problem comprehension, high flexibility, broad problem recognition and social tolerance, such as dolphins, even with their physical limitations, can still use and establish tool use in their groups while others, such as the gorillas, do not show regular tool behavior despite their distinct manual manipulative abilities. The different factors are in part necessary or limiting factors for the development of tool behavior, their presence automatically generates specific forms of tool use.

In the next chapter I will discuss the cognitive factors breadth of problem recognition, problem comprehension and flexibility by illustrating individual examples of tool use among animals through Cognigrams.

18 Problem-Solution Distances in Animal Tool Behavior

Animal tool behavior is generally defined as a behavior form with unmodified objects, rarely with prepared objects, that usually occurs in a subsistence context and is instinctive or can be, at least partially, learned. The cognitive processes involved in this behavior are rarely differentiated. This chapter looks at what differentiates proto-tool use from true-tool use; it examines how identical goals can be reached through different methods and how similar actions with different goals require distinctive thought-processes. The goal is to arrive at a distinctive picture of the cognitive capabilities in animal tool behavior, which will then serve as the foundation for a comparison with the development of human tool usage and behavior.

Proto-Tool Use: e.g. The Drosselschmiede

If and how proto-tool use can be distinguished from true-tool use and whether it is constructive to treat them separately has been the subject of numerous discussions (e.g. Parker& Gibson 1977; Beck 1980; Becker 1993; see Chapter 14). Lefebvre et al. (2002) found differences in the development of areas of the brain of birds working with true-tools versus those using proto-tools. Proto–tool behavior is only treated briefly in this paper; it is important to take look to see if and how it can be distinguished from true-tool behavior with respect to problem perception and foci of attention.

Different species of birds demonstrate proto-tool use in a subsistence context by holding on to their prey through spearing or pinning it down, by dropping prey with hard shells onto hard surfaces to open them and by hammering prey onto an anvil as in the example of the "Drosselschmiede" (Lefebvre et al. 2002, 948-952; Becker 1993, 46-52). Similar use of an anvil was also observed in multiple species of wrasse (*Coris angulata*, *Cheilinus lunulatus* and *Cheilinus trilobatus*); the fish beat sea urchins onto large rocks to break them open (Fricke 1971, 1973 in Becker 1993, 37). The most prominent anvil behavior among mammals was observed among the tufted capuchin (*Cebus apella*) (Becker 1993, 81-83). Due to its frequency, the anvil use in subsistence contexts will be used as an example for proto-tool use behaviors.

The external catalyst for the use of a "Drosselschmiede" (Fig. 29) is a snail shell that needs to be opened. The thought and action chain only involves three phases: the search for a suitable anvil, opening and then consuming the snail. Three foci of attention are activated in the action process involved in this behavior: The active focus of the perceiving and acting subject, the passive object focus on the snail and the second, also passive, object or location focus on the anvil. The animal carrying out the action must include the passive effect or changing effects of beating the objects (anvil or snail) in its considerations, but it only has to control its own action as the active factor in the action process. It is not necessary to coordinate the subject's own actions with the active effects of another medium. The subject feels a basic need; the subject acts using passive objects; the subject satisfies its needs: There is no transfer of the active moment.

Proto-Tool Use: "Drosselschmiede"

0. Perception basic need: food
0a. Perception subproblem 1: need of a snail
0b. Perception subproblem 2: suitable place to open the snail is necessary

PHASE I: Search for anvil
1. Transport of snail
2. Selection of anvil

PHASE II: Opening the snail
3. Positioning of the individual
4. Holding the snail in the beak
5. Hammering (repeatedly)

PHASE III: Satisfaction of need
6. Consumption

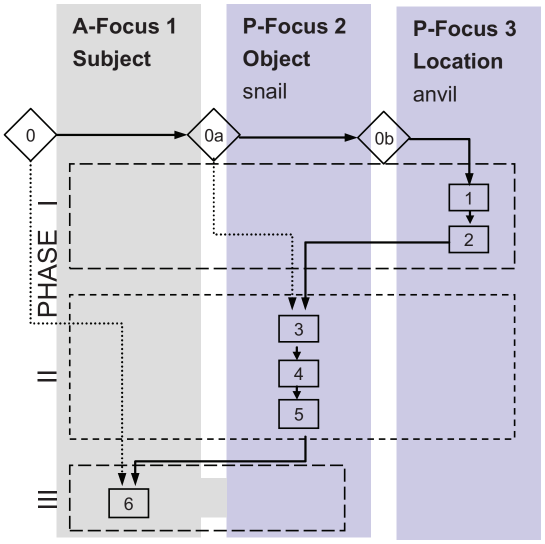


Fig. 29 Cognigram of a "Drosselschmiede" e.g. for sing thrushes (*Turdus philomelos*) and redwings (*Turdus iliacus*) (comp. Becker 1993, 46-47).

The next example of true-tool use, hammering an egg with a stone to open it (Fig. 30), is similar in process and result, yet different. The external catalyst of behavior is the discovery of an egg, the thought and action chain is also limited to three phases. Although there are also three foci active in the course of the action process, the egg is the only passive object being acted *upon* or being changed. The third focus, the tool, is active like the subject focus. The animal carrying out the action must consider the passive variability of the object (egg) when cracking the egg with a stone. It must control the active forces, its own actions as well as the effect of the tool. It is necessary to coordinate the animal's own actions with the active effects of the medium. The subject feels a basic need, the subject acts indirectly *through* a tool on a passive object; the subject satisfies its need: A transfer of the active moment from the subject to the medium takes place in the act of opening the egg. In this example, the cognitive problem-solution distance is expanded with two foci of attention compared to the example of the "Drosselschmiede", which involved only one active focus. The difference is illustrated in the cognigrams: For the "Drosselschmiede" (Fig. 29), the subject focus influences one object focus, when hammering an egg (Fig. 30), both the subject and the tool foci influence the object focus.

Tool use: Hammering an egg with a stone to open it by *Neophron percnopterus* (after van Lawick-Goodall & van Lawick-Goodall 1966)

0. Perception of basic need: food
0a. Perception subproblem 1: need of an egg
0b. Perception subproblem 2: tool necessary

PHASE I: Search for tool
1. Search for suitable stone

PHASE II: Transport of tool
2. Transport to egg

PHASE III: Opening the egg
3. Positioning of the individual
4. Holding the stone in the beak
5. Hammering / Throwing the stone on the egg (repeatedly)

PHASE IV: Satisfaction of need
6. Consumption

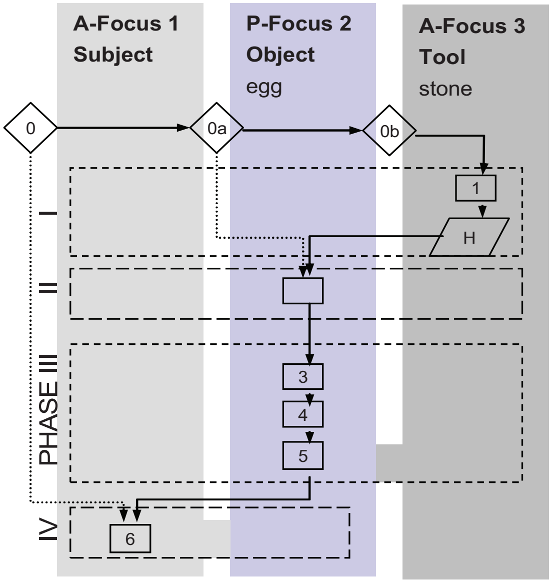


Fig. 30 Cognigram for an Egyptian vulture (*Neophron percnopterus*) hammering an egg with a stone.

White fronted and tufted capuchin monkeys (*Cebus albifrons* and *Cebus apella*) demonstrate a seemingly intermediate form of cracking open nuts, oysters and fruits with objects of the same kind. Since the acting subject does not differentiate between the object and the tool, as it did in the previous examples, the analysis of behavior in the cognigram must look different (Fig. 31). Only two foci of attention are activated, the subject's focus and the focus of the identical objects. Due to the selection of e.g. two nuts, the object focus is split into two sub-foci with identical significance. There is no sequence to handling the objects, nor is there a differentiation between the active object and the object being acted upon. At the end of the action, one or the other nut, oyster or fruit, or both is opened and eaten. The subject is not in control of the result. The only active moment that is controlled in this thought and action chain is the subject's own actions, it is not necessary to coordinate the actions and the active effect of the medium. A transfer of the active moment to a tool does not take place. In this case, we assume that the animals searched for the food. However, if the animals happened upon the objects, fruits, nuts or oysters, by chance, then the number of phases is reduced to two.

Proto-hammering by *Cebus albifrons* und *Cebus apella*

0. Perception basic need: food
0a. Perception subroblem 1: need of nut / oyster

PHASE I: Collection of nuts / oysters
1. Searching and finding of nuts / oysters

PHASE II: Cracking open nuts / oysters
2. Holding nut / oyster 1 in one hand
3. Holding nut / oyster 2 in the other hand
4. Cracking the nuts / oysters against each other (repeatedly)

PHASE III: Satisfaction of need
5. Consumption

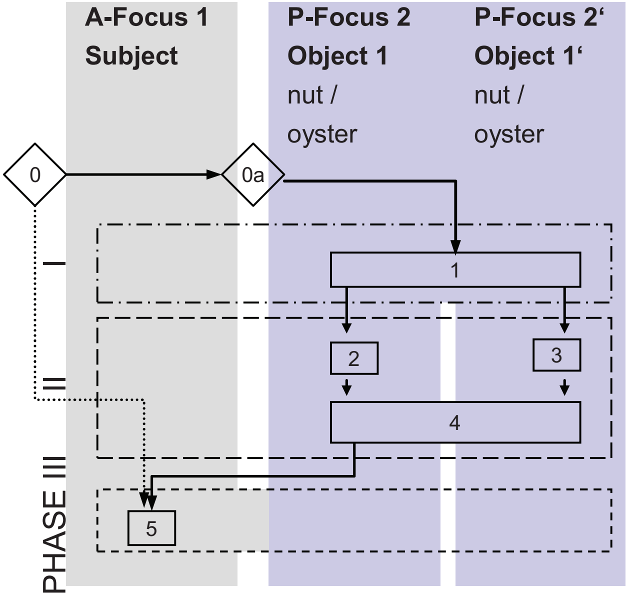


Fig. 31 Cognigram for different species of capuchin monkeys (*Cebus*) cracking open nuts, oysters or cumare fruits with an identical object (after Becker 1993).

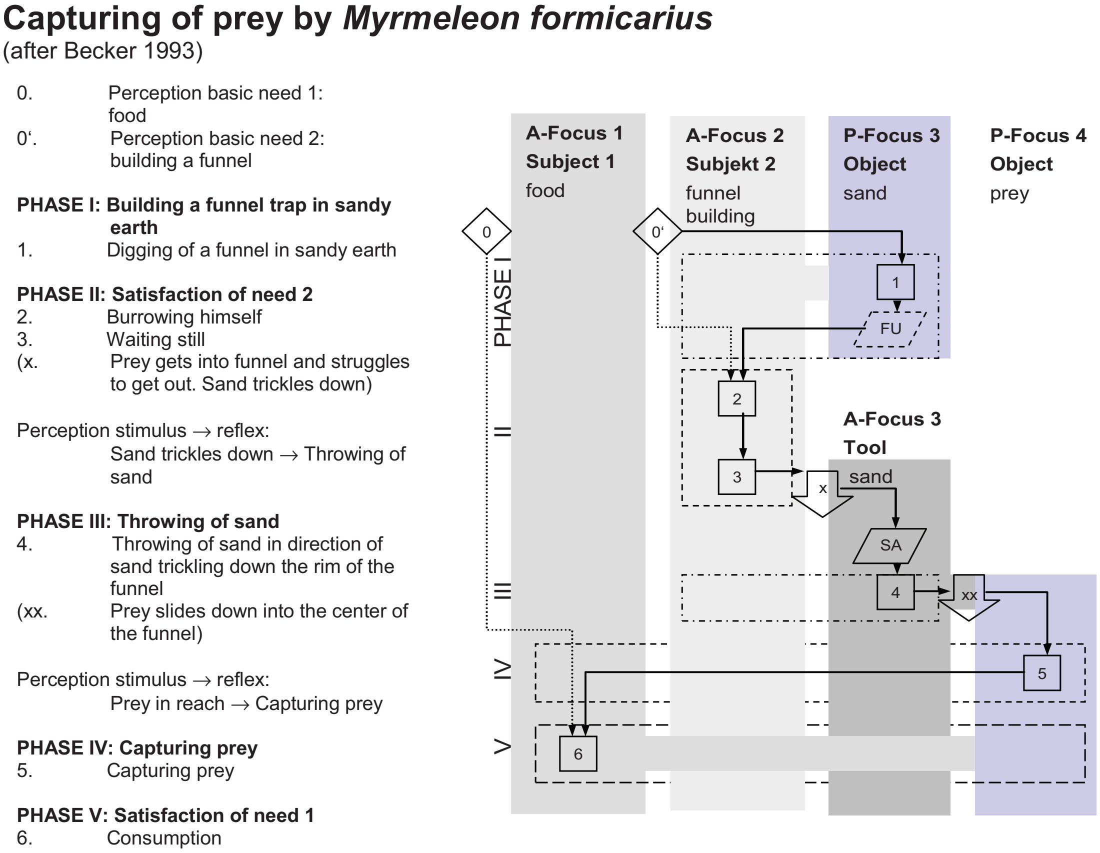
Although, at first glance, the behavior of the species of *Cebus* looks like borderline tool use because both elements are handled and cracked against each other, a second glance shows that the behavior can be rated as a simple form of proto-tool use with only two foci of attention.

Tool Use and Intention: e.g. the Ant Lion

The definition of tool behavior is dependent on the acting subject's intention and what it aims to achieve with its actions; this is demonstrated using the example of the ant lion (*Myrmeleon formicarius* and *Euroleon nostras*), whose hunting behavior is defined as explicit tool behavior (Beck 1980, 16; Becker 1993, 26). The doodlebugs (larvae of the ant lion) build funnel shaped traps in the sandy earth (fig. 32) in which they trap their prey. They dig themselves into the earth at the base of the funnel and wait for an ant to fall into the trap and slide down to them. If the prey tries to save itself by clinging to the lip of the funnel, thereby loosening grains of sand that fall down into the funnel and onto the ant lion, it reflexively throws sediments into the direction from which the grains of sand came. The thrown sand causes the walls of the funnel to become instable and the prey slides down into the center (Beck 1980, 14; Becker 1993, 25-27; personal observation).

Fig. 32 An ant lion's funnel trap (Photo: Haidle)

If we define the ant lion's behavior as capturing prey using tools (fig. 3), then it becomes clear that capturing prey for food is multi-phased behavior that encompasses multiple foci of attention. However, the action sequence is cognitively less complex than it seems.



Capturing of prey by *Myrmeleon formicarius*
(after Becker 1993)

0. Perception basic need 1: food
0'. Perception basic need 2: building a funnel

PHASE I: Building a funnel trap in sandy earth
1. Digging of a funnel in sandy earth

PHASE II: Satisfaction of need 2
2. Burrowing himself
3. Waiting still
(x. Prey gets into funnel and struggles to get out. Sand trickles down)

Perception stimulus → reflex:
Sand trickles down → Throwing of sand

PHASE III: Throwing of sand
4. Throwing of sand in direction of sand trickling down the rim of the funnel
(xx. Prey slides down into the center of the funnel)

Perception stimulus → reflex:
Prey in reach → Capturing prey

PHASE IV: Capturing prey
5. Capturing prey

PHASE V: Satisfaction of need 1
6. Consumption

Fig. 33 Cognigram of the behavior of the ant lion, interpreted as capturing prey using tools.

Capturing of prey by *Myrmeleon formicarius*

(after Becker 1993)

0. Perception basic need 1: building a funnel

PHASE I: Building of a funnel trap in sandy earth
1. Digging of a funnel in sandy earth

PHASE II: Satisfaction of need 2
2. Burrowing himself
3. Waiting still

(x. Prey gets into funnel and struggles to get out. Sand trickles down)

Perception stimulus → reflex:
Sand trickles down → Throwing of sand

PHASE Ia: Throwing of sand
4. Throwing of sand in direction of sand trickling down the rim of the funnel
(xx. Prey slides into the center of the funnel)

0'. Perception basic need 2: food

Perception stimulus → reflex:
Prey in reach → Capturing prey

PHASE I': Capturing prey
1'. Capturing prey

PHASE II': Satisfaction of need 2
2'. Consumption

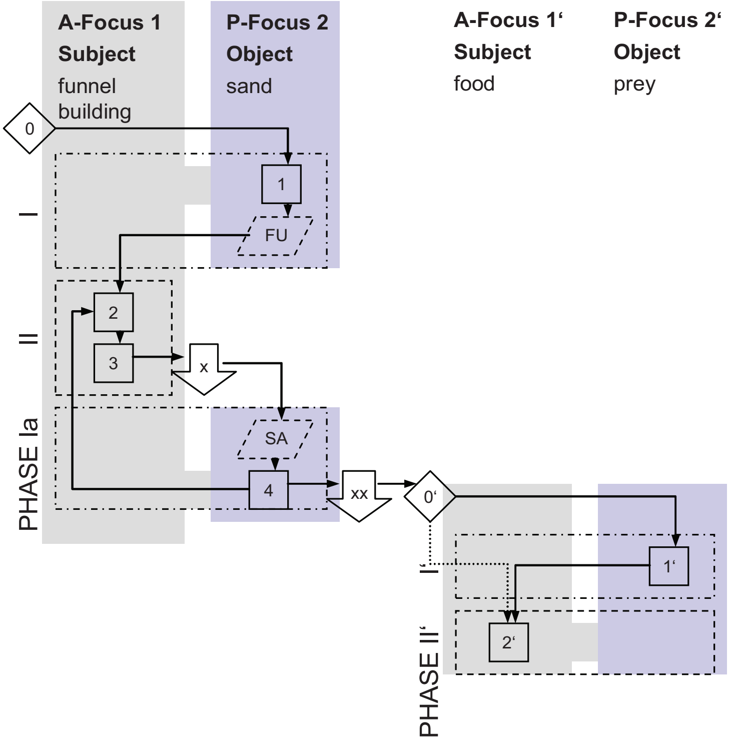


Fig. 34 Cognigram of the behavior of ant lions interpreted as two separate thought and action processes, funnel building and hunting.

The different foci are not activated through the identification of subproblems, but through instinctive basic needs and the perception of external impulses. Building the funnel is not an anticipatory or intentional reaction to the basic need for sustenance – the funnel is not build in order to capture prey in the future - it is an independent basic need that must be satisfied. If sand trickles into the funnel, the ant lion reflexively throws sand in the direction of the trickle, again, probably not to intentionally hit the prey. If an ant finally lands at the bottom of the funnel, the first basic need is satisfied without the ant lion anticipating it or having become intentionally active. The tool and object focus of the prey are not activated from the beginning; only independent external impulses, which are not based on the subject's intentional actions, activate these foci for a short period of time.

In contrast, according to the definition by Alcock and Beck, orcas (*Orcinus orca*; Mason 2005) that vomit food to bait birds may not be considered as tool behavior since the bait is an internal product of the subject and does not come from the surroundings (comp. Chapter 14). The subproblem “bait” is identified, but a new focus of attention is not activated to use resources from the subject’s surroundings, the problem is solved through its own actions (vomiting) (fig. 35). However, here the subject does not directly act on the target object “seagull”; it is not spit from the sky; the vomit converts into the medium through the temporal separation of the act of vomiting and its resulting effect. The active moment is transferred to the bodily product as the medium.

The interpretation of the hunting strategies, carried out by ant and worm lions, as successive and intentional thought and action chains involved in tool behavior (fig. 33), as argued by Beck (1980) und Becker (1993), is therefore not correct. In fact, they represent two separate, intentionally independent processes with individual basic needs that are neither accidentally, nor intentionally, interlocked. The thrown sand is a tool only because it was thrown, not because it is a tool in and of itself. It is used outside of the thought and action chain, which it initiates. To interpret both processes as a causal thought and action chain with the goal to acquire food, corresponds to the human way of thinking.

The Controlled Use of Tools: e.g. Baiting …

As opposed to the ant lion throwing sand, which is generally characterized as tool behavior, the tool character of an object being used in baiting is still the subject of much discussion. Lefebvre et al. (2002, 948) place the baiting behavior by birds into the category of proto-tool use, Becker (1993, 59-62) and Beck (1980, 28-29) accept it as true tool use.

Different species of heron, also a black kite and an Australian rainbow bee eater, were observed as they first searched for and caught bread crumbs, feathers, worms or insects, and then placed these onto the water surface in order to bait fish. Prytherch (1980 in Becker 1993, 61) observed the squacco heron (*Ardeola ralloides*), used here to demonstrate this behavior, which caught 16 insects in a period of 20 minutes and then used them to catch fish. In this case, only one basic need can be identified, the need for food (fig. 35). Based on this need, two subproblems are recognized and the corresponding foci of attention activated. The insects are caught and placed on display with the intention to bait prey. The insect is an external, independently moving object that is used for a specific process. However, in the process of baiting, when the insect medium tempts (psychologically) the target object, the fish, it is not handled by the subject, only observed. A transfer of the active, effective moment from the subject to the medium takes place, yet the subject has no direct influence on the effectiveness of the tool; it only controls it through selection and placement. Therefore, baiting with insects and bread is interpreted as borderline tool behavior, tool implementation as opposed to tool use.

Proto - tool use: Vomiting food to bait birds by *Orcinus orca*

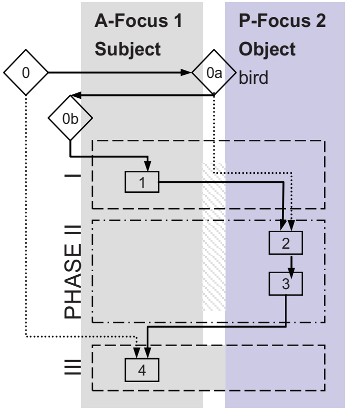
(after Mason 2005)

0. Perception basic need: food
0a. Perception subproblem 1: need of bird
0b. Perception subproblem 2: bait necessary

PHASE I: Provisioning of a bait
1. Vomiting food

PHASE II: Baiting a bird
2. Waiting still and observing
3. Baiting the bird

PHASE III: Satisfaction of need
4. Consumption



Tool use: Baiting with insects by *Ardeola ralloides*

(after Beck 1980; Becker 1993; Lefebvre et al. 2002)

0. Perception basic need: food
0a. Perception subproblem 1: need of fish
0b. Perception subproblem 2: bait necessary

PHASE I: Provisioning of a bait
1. Catching of insect

PHASE II: Baiting a fish
2. Positioning of insect on the water surface
3. Waiting still and observing
4. Baiting the fish

PHASE III: Satisfaction of need
5. Direct consumption

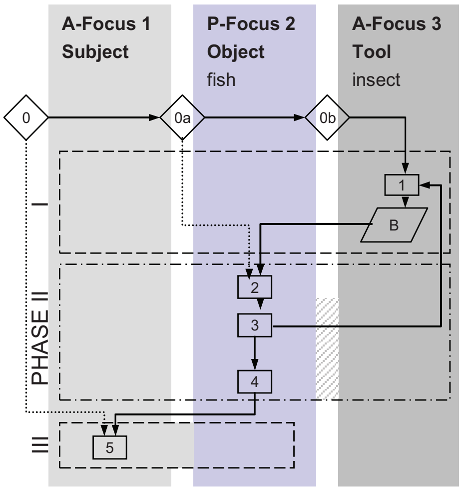


Fig. 35 Cognigrams of baiting by orcas (*Orcinus orca*) and squacco herons (*Ardeola ralloides*).

It makes sense, that the use of the subject's own bodily products is not considered as tool use because the subject does not take external measures into consideration to solve the problem: The distance between problem and solution is shorter. Since, in this case, the bodily product is not used directly because its effect is delayed; it is possible to assume a belated interpretation as an object or tool. No matter which point of view one supports in this case, it has become increasingly obvious that it is not easy to make a clear differentiation between tool behavior and other borderline behavior.

The impulse in both types of baiting is not a predefined target object that activates the thought and action chain, as in the case of the "Drosselschmiede" or the use of a hammer to open an egg, but an undefined external or internal stimulus, the anticipation of a reward. This behavior represents an investment whose continuing effect on an object cannot be continuously observed and whose conclusion is uncertain.

... And Antler Adornments in Deer

Antler adornment by different species of deer (Beck 1980, 37-38, Fig. 1-1; Becker 1993, 78) is an example of how the classification of such borderline cases of behavior, and the intention behind it, is dependent on the human observer. It is possible to observe this phenomenon among the Peré David's stags (*Elaphurus davidianus*); primarily from July until September, the stag's antlers can be seen covered with plants or mud (Beck 1980, 38). The trigger for this behavior is just as unknown as the intention behind it. The phenomenon is often interpreted as intentional behavior in a rutting context; however, it remains unclear whether the intention is to impress a competitor or to attract female animals, in short, what is the target object. Beck (ibid.) interprets the accumulation of hay or plants with the antlers as an accidental by-product during feeding. At the same time, he considers the affixation of mud to the antlers to be an intentional action, even though the time of year when this predominantly occurs does not completely correlate with the rutting season in June and July.

Depending on whether one sees the behavior as target-oriented in a rutting context, as accidental in a feeding context or as target-oriented in some other context, the hangings can be interpreted as tools, by-products or intentional products without tool-character. If one assumes that the hangings were not intended to be used as adornments, then they could be accidental by-products of feeding or aggression reduction. For the latter, it is quite possible that stags visit a bush or pool of mud in order to take out their aggression on it: This behavior would activate a second focus of attention (fig. 36a). The satisfaction of the basic need occurs, when the subject acts on the object (bush, pool of mud), only the subject is active. Whether female deer are possibly attracted by these hangings is irrelevant for this behavior with which a basic need is satisfied: No other focus of attention is activated for the female deer, the doe, within this action chain.

Adorning (?) antlers with mud or plants by *Elaphurus davidianus*

(after Beck 1980)

a)

0. Perception basic need:
rejection, restlessness during rutting, itching of the antlers

0a. Perception subproblem 1:
need of something to reduce aggression

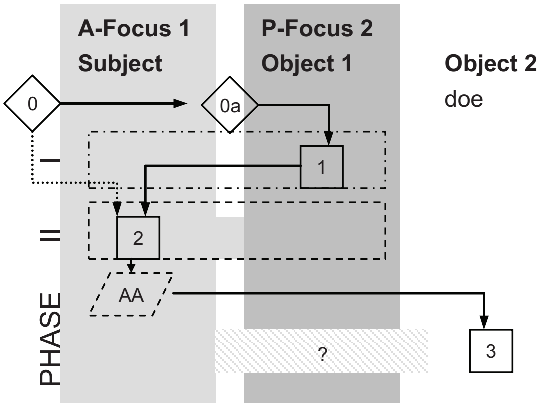
PHASE I: Search for suitable object

1. Search for mud, plants, etc.

PHASE II: Satisfaction of need

2. Running antlers through mud, rubbing antlers against plants, etc.

(3. ‚Adorned‘ antlers attract doe)



b)

0. Perception basic need:
mating

0a. Perception subproblem 1:
need of a doe

0b. Perception subproblem 2:
increasing perceptiveness

PHASE I: Search for raw material

1. Search for mud, plants, etc.

PHASE II: Production of adornment

2. Running antlers through mud, rubbing antlers against plants, etc.

PHASE III: Awaking attention

3. Prancing with adorned antlers
4. ‚Adorned‘ antlers attract doe

PHASE IV: Satisfaction of need

5. Mating

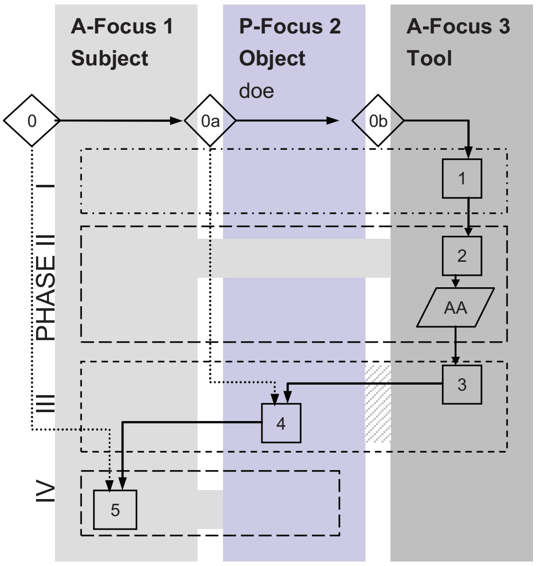


Fig. 36 Cognigram of adorning antlers with mud or plants among Peré David's stags: a) as an unintentional by-product of feeding, b) as target-oriented tool use.

Depending on whether one sees the behavior as target-oriented in a rutting context, as accidental in a feeding context or as target-oriented in some other context, the hangings can be interpreted as tools, by-products or intentional products without tool-character. If one assumes that the hangings were not intended to be used as adornments, then they could be accidental by-products of feeding or aggression reduction. For the latter, it is quite possible that stags visit a bush or pool of mud in order to take out their aggression on it: This behavior would activate a second focus of attention (fig. 36a). The satisfaction of the basic need occurs, when the subject acts on the object (bush, pool of mud), only the subject is active. Whether female deer are possibly attracted by these hangings is irrelevant for this behavior with which a basic need is satisfied: No other focus of attention is activated for the female deer, the doe, within this action chain.

If we assume that the hangings are intentional and meant as adornment, then the actions must be interpreted as true tool behavior with a tool, which the subject controls. The active, effective moment is transferred from the subject to the ornament medium, or at least it is expanded by the addition. Depending on the impulse, the thought and action chain must be extended by one or two phases. If the trigger is one or more specific doe, then the total process may encompass four phases (fig. 36b); if an internal stimulus activates the actions, then the number of phases, including the search for a doe, increases to five. The breakdown of behavior in the cognigram is very dependent on the point of view of the observer and the phrasing of the behavior description: Adornment – effective or hanging – neutral?

From Toy to Tool: Two Uses for a Feed Basket

It is only possible for specific behavior in new context to develop from one form of behavior by displacing the target goal and extending the foci of attention. The Grevy Zebra in the Brookfield zoo is an example of this (Beck 1980, 154-155, fig. 4-1) (fig. 37). A similar displacement of goals - from antler hangings to rutting ornamentation – could also be taken into consideration in the case of the stags.

The young male zebra (*Equus grevyi*) came to the Brookfield zoo, already exhibiting pronounced playful behavior by throwing feed baskets. If you break down this behavior in a cognigram, then the basic need could be play or entertainment, which is satisfied with the basket (fig. 37a). Beside the subject focus, the attention is on the tool, the basket. The subject's own actions must be coordinated with the effects on the basket. The active moment is transferred from the subject to the basket as the medium. It is not only the subject's own unusual movement or behavior which fascinates the zebra, but its extension through the tool and its "actions". It is difficult to accept the basket as a tool; however, if we alter the basic need to that of clearing out a stuffed nose and replace the basket with a probe, which must be manipulated, (fig. 42) then the result is an identical action chain. The difference is that the probe functions physically, the basket psychologically.

Toy of *Equus grevyi* (after Beck 1980)

a)

0. Perception basic need: distraction / playing
0a. Percepton subproblem 1: need of toy

PHASE I: Search of toy
1. Search and Finding of feed basket

PHASE II: Playing
2. Brandishing / throwing around of basket

PHASE III: Satisfaction of need
3. Distraction
3. Brandishing frightens unfriendly mares

b)

0'. Perception basic need: playing / impressing mares
0'a. Perception subproblem 2: frightening mares
0'b. Perception subproblem 1: need of tool

PHASE I: Search for tool
1'. Search and finding of food basket

PHASE II: Frightening mares
2'. Brandishing / throwing around of basket
3'. Brandishing frightens unfriendly mares

PHASE III: Satisfaction of need
4'. Impressing

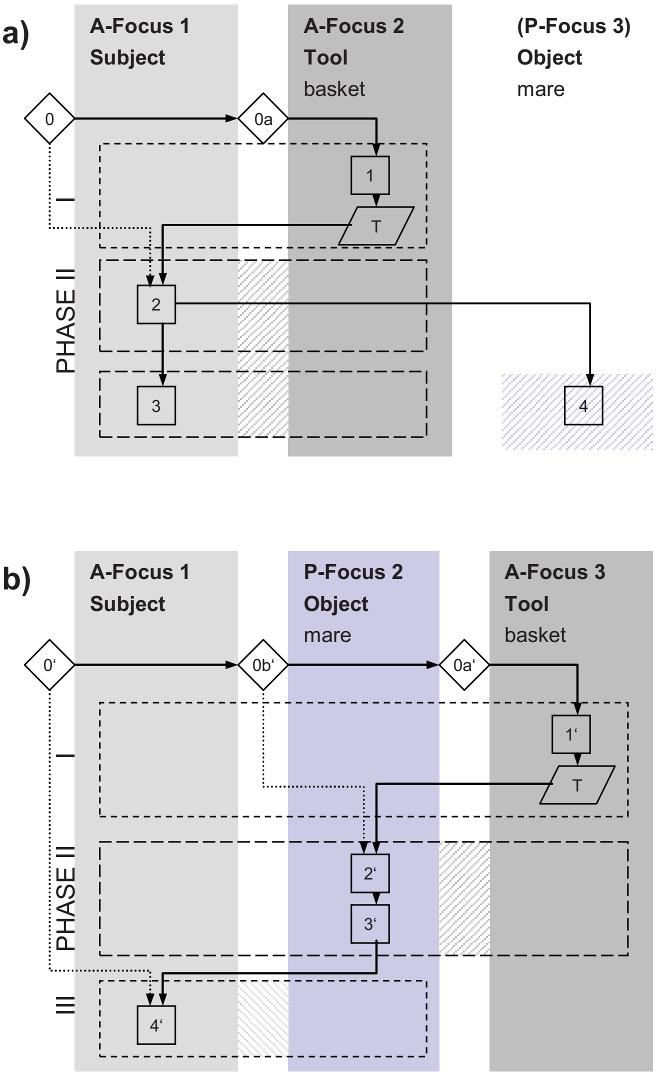


Fig. 37 Cognigram of the utilization of a feed basket by a Grevy zebra: a) as a toy, b) exaptation of the same behavior used to impress.

In its new home in the Brookfield zoo, the playful zebra encountered two older female animals, which seemed to dominate it. Throwing the basket scared the older zebras and caused them to run away. The young male animal seemed to recognize the reaction and how it came to be because it began to stalk the older mares with the basket (Leja in Beck 1980, 154). The phenomenological identical behavior was carried out with a new goal: The basic need changed from the need to entertain, to the need to impress (fig. 37b). The target object of the action changed from the subject itself to the mares. Three foci of attention are activated in the operation chain; the tool is controlled in order to achieve the desired affect from the mares. The subject is satisfied when the mares run away and the subject is dominant. As in the case of the antler ornaments (s.a.), the number of phases depends on the trigger of the behavior: If the mares are the external impulse, then the action is restricted to three phases; if an inner stimulus triggers the action and the mares must be located first, then a fourth phase is activated.

In the zebra example, behavior developed in a specific context is found to be effective in another context and is thereafter used in the new context. This is not an adaptation – the behavior (throwing baskets) is developed to master a certain situation (impressing the mares) – but an exaptation of behavior (comp. Gould & Vrba 1982). From the cognitive point of view, this case is interesting because, initially, the behaviors seem identical; however, the problem-solution distance is extended due to the recognition of sub-problems and the activation of a new focus of attention. The inclusion of a different target object in place of the subject and the resulting activation of three foci of attention have only been observed among ungulates in the case of the zebra and - if the behavior is interpreted as use of ornamentation – in the use of antler adornments among some species of deer.

Production of Tools: e.g. Leaves as Scoop and Sponge

The production of tools, which requires an additional increase of the problem-solution distance, was only treated as a possible side-aspect in the case of antler hangings among stags. While the stone, once it was found and transported to the egg, was used immediately as a hammer to open the egg, many tools have to be produced first by altering their raw form. Beck (1980, 105) distinguishes four different production types in animal tool behavior. The simplest form of manipulation is to detach the intended tool from its substrate: Plucking a leaf from a tree, breaking off a branch from a bush or digging up a stone. Once the object is free and manageable, tool production can continue. Reductive actions are actions in which excessive parts are removed, e.g. defoliating, decorticating, and cutting a probe. Additive action or the combination of elements has so far only been observed by animals in captivity (comp. Chapter 19). Reforming a raw form into a functional tool, e.g. has been observed in different groups of chimpanzees who use leaves as sponges and folded leaves (fig. 38) as scoops.

Production and use of a folded leaf to scoop water by *Pan troglodytes*
(after Tonooka 2001)

0a. Perception stimulus:
knothole filled with water
0. Perception basic need: drinking
0b. Perception subproblem 2: tool to
scoop water necessary

PHASE I: Search for raw material
1. Search for adequate leaf

PHASE II: Production of tool
2. Breaking off the leaf / leaves
3. Putting in the mouth
4. Multiple folding
5. Removing from mouth

PHASE III: Use of tool
6. Dipping the folded leaf into the water

PHASE IV: Satisfaction of need
7. Consumption

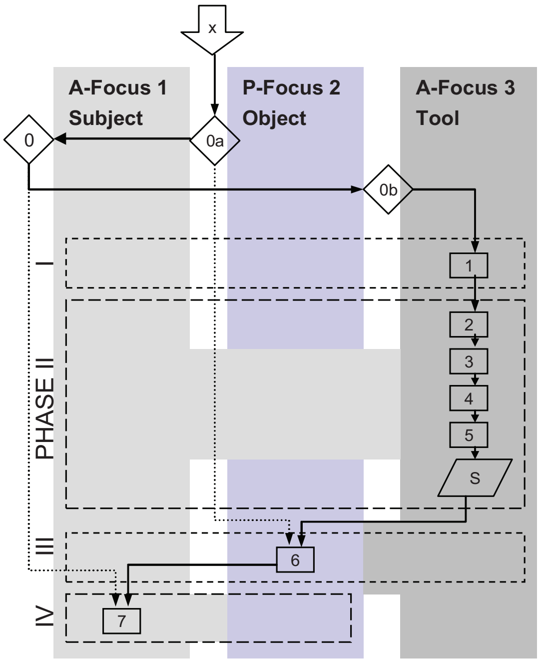


Fig. 38 Cognigram of the production and application of a folded leaf used to scoop water among chimpanzees.

Infrequently, unaltered leaves may be used as simple spoons; leaves are carefully chewed and crumpled into leaf sponges or folded in the mouth to increase their scooping potential. The thought and action chain (fig. 38) is thereby extended by an additional phase of production. The result focuses on the target object, the thought and action steps involved in the chain, however, are only focused on the tool and its raw material form. To solve the problem, the impulse to directly go for the target object, is further delayed. A subject must principally be able to recognize an object's potential from looking at its raw shape and that it is possible to remove the potential tool from its substrate in order to include it in a production phase.

Tools for a Secondary Goal: e.g. Nose Protection

So far, we have only addressed tool behavior in which the tool was used as medium to directly impact the satisfaction of the basic need. In this example, I will show how the tool is used to resolve a secondary problem. Off the West-Australian coast, dolphins use their nose to stir up the ocean floor in search of food. In order to protect the skin of their nose from sharp particles in the sediment, some animals developed a habit of tearing off living sponges and putting them over their nose while searching for food (fig. 39).

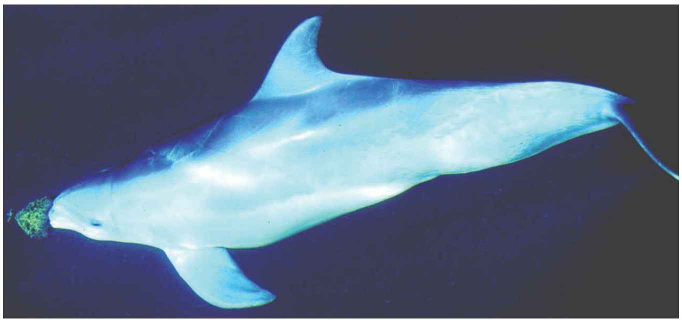


Fig. 39 Dolphin (*Tursiops sp.*) off the West-Australian coast with a sponge, searching for food (from Krützen et al. 2005)

So far, this behavior has only been observed among a group of closely related female animals in Shark Bay. However, it is highly probable that ecological as well as genetic factors cannot be held accountable for the distribution of this behavior (Krützen et al. 2005).

Use of a sponge as nose protection by *Tursiops sp.*
(after Krützen et al. 2005)

0. Perception of basic need: food
0a. Perception subproblem 1: access to food
0b. Perception subproblem 2: sediment of sea floor hurts nose
0c. Perception subproblem 3: protection necessary

PHASE I: Search for tool
1. Search for appropriate sponge

PHASE II: Production of tool
2. Detaching of sponge
3. Putting it over the nose / protection

PHASE III: Scaring up prey / use of tool
3. Putting it over the nose / protection
4. Scaring up prey from ocean floor
5. Catching the food

PHASE IV: Satisfaction of need
6. Consumption

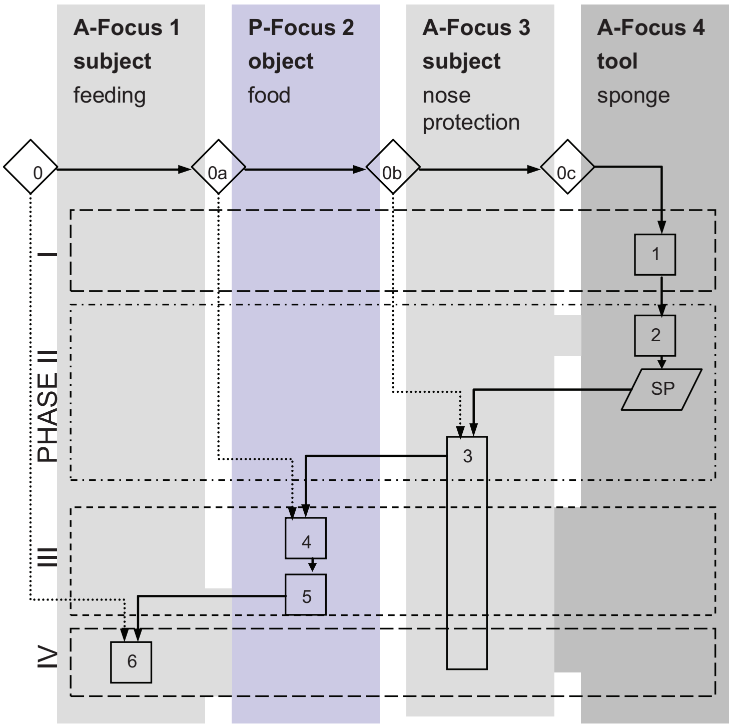


Fig. 40 Cognigram of sponge use while searching for food, in wild Australian dolphins.

In the course of the problem perception to satisfy the basic need “food", a sub-focus is activated alongside the object focus “food”, the desire to avoid damaging the nose and to avoid pain (fig. 40). A tool is not necessary to satisfy the basic need for the object “food” – ten other behavioral forms are known aside from the use of sponges (Krützen et al. 2005, 8939) – however, the additional need to protect the skin during the search for food is satisfied using a medium, for which a fourth focus of attention must be activated. The impulse for this behavior – the specific external irritation or the anticipation of a hurt nose and, thereby an internal stimulus – remains unclear. The behavior only occurs in a subsistence context although it is not directly coupled with the solution to the subsistence problem. The cognitive distance between the basic problem and the solution is clearly extended: While satisfying the basic problem, another comparatively insignificant secondary problem is recognized and a solution is found, thereby delaying the satisfaction of the primary need.

Tools for a Higher Goal: e.g. The Cleaning Probe for Children

While the dolphin’s nose guard is a secondary need that is identified, pursued and satisfied, another type of tool use was documented among gorillas and chimpanzees where the subject's basic need is the well-being of another individual.

Tool use: Probe for cleaning the nose by *Pan troglodytes*
(after Whiten et al. 1999; 2001)

0. Perception basic need: breathing freely
0a. Perception subproblem 1: tool necessary

PHASE I: Search for raw material
1. Search for a small twig

PHASE II: Production of tool
2. Breaking off the twig
3. Possible modification of the twig

PHASE III: Cleaning of the airways
4. Inserting probe into the nostril
5. Moving probe inside the nostril

PHASE IV: Satisfaction of need
6. Sneezing / Cleaning of the airway

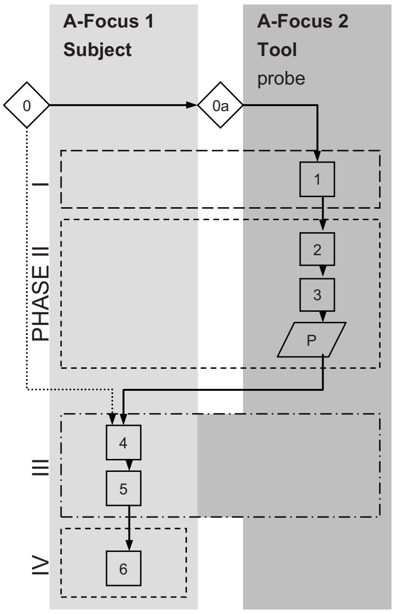


Fig. 41. Cognigram of the use of a probe for cleaning the nose among chimpanzees.

Usually, tools used in a hygiene context are used by and on the subject itself (fig. 41). The subject recognizes a basic need and the necessity of a tool. Its own actions and the effect of the tool are controlled simultaneously. Only two foci of attention are activated. Fontaine et al. (1995) describe an extension of this behavior of a female western lowland gorilla (*Gorilla gorilla gorilla*) at the Centre International de Recherches Medicales de Franceville in Gabon. The animal recognizes a need to use a tool for cleansing on its sleeping child and not for personal hygiene, for which an additional focus of attention is activated (fig. 42).

The problem-solution distance remains the same although different intentions may be responsible for the action. Either the subject wants to play and uses the young animal as a tool or toy that is manipulated using a second tool. Or the subject has recognized the other individual’s basic need, a need that the young animal does not recognize itself, and handles the child as a tool to satisfy its own basic needs (comp. Chapter 19).

Probe to clean the ears and bellybutton of a young by *Gorilla gorilla gorilla* (after Fontaine et al. 1995)

0. Perception basic need:
satisfying the basic need of the young (?)
or distraction (?)
0a. Perception subproblem 1:
basic need young → cleanliness (?)
or toy necessary (?)
0b. Perception subproblem 2:
tool necessary

PHASE I: Search for raw material of tool 2
1. Search for a small twig

PHASE II: Production of tool 2
2. Breaking of the twig
3. Modification of the twig

PHASE III: Manipulation of tool 1 Cleaning of the ears and the bellybutton
4. Inserting probe into ears / bellybutton of the young
5. Moving the probe
6. Removing dirt

PHASE IV: Satisfaction of need
7. Young is clean

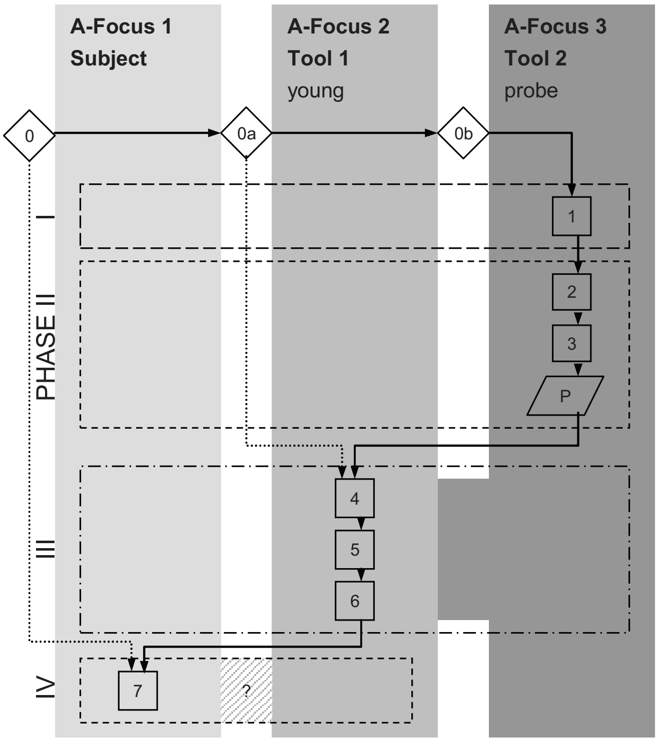


Fig. 42. Cognigram of the use of a probe to clean the ears and bellybutton of a younger animal by a western lowland gorilla.

The example of partner dental hygiene in chimpanzees cannot be interpreted as a game (Beck 1980, 91; comp. Chapter 17). It shows that the individual basic need in great apes, which initiates the thought and action chain, can be geared to satisfy the needs of another individual. The impulse for this behavior is definitely a specific external stimulus, the sleeping young animal, recognized either as object or subject, as well as the group member suffering from a toothache.

Multifunctional Tools: e.g. the Stick

It is not self-evident that one category of objects can function as tools in different action chains, possibly even in different contexts: Such behavior is rare in animals and can be predominantly observed among the great apes. Especially if the behavior does not take place within established social parameters and develops slowly into learned behavioral routines, but when it occurs individually and spontaneously based on the situation, then it requires a high degree of abstract thinking about the object and the situation as well as flexibility. One example of the same tool being used in two different thought and action chains and contexts was observed among the western lowland gorillas (Breuer et al. 2005).

Fig. 43 A female western lowland gorilla using a stick for support at the edge of a swamp while harvesting water plants (from Brewer et al. 2005)

While searching for food near the edge of a swamp, a female animal searched for a strong, dead branch, broke it off and rammed it into the soft ground using both hands. Afterwards, she supported herself on the branch to avoid loosing her footing on the slippery shore while harvesting and eating the water plants (Fig. 43). After satisfying her hunger, she pulled out the branch and placed it onto the swamp. She then balanced on the stick to cross the swamp and avoid sinking into the soft ground.

Using a stick for support and as a bridge by *Gorilla gorilla gorilla*

(after Breuer et al. 2005)

0. Perception basic need: food
0a. Perception subproblem 1: need of water plants
0b. Perception subproblem 2: shore of the swamp is splippery, staying dry
0c. Perception subproblem 3: support is necessary

PHASE I: Search for raw material
1. Search for suitable branch

PHASE II: Production of support
2. Breaking of the branch
3. Ramming it in the soft ground using both hands

PHASE III: Use of tool
4. Supporting herself on the branch
5. Harvesting the water plants with the hand

PHASE IV: Satisfaction of need
6. Consumption

0‘. Perception basic need: crossing the swamp
0‘a. Perception subproblem 1: staying dry
0‘b. Perception subproblem 2: bridge necessary

PHASE V: Production of the bridge
1‘. Picking up the same branch
2‘. Pulling the branch out of the swamp
3‘. Positioning the branch on the swamp

PHASE VI: Crossing the swamp
4‘. Balancing on the branch

PHASE VII: Satisfaction of need
5‘. Swamp is crossed

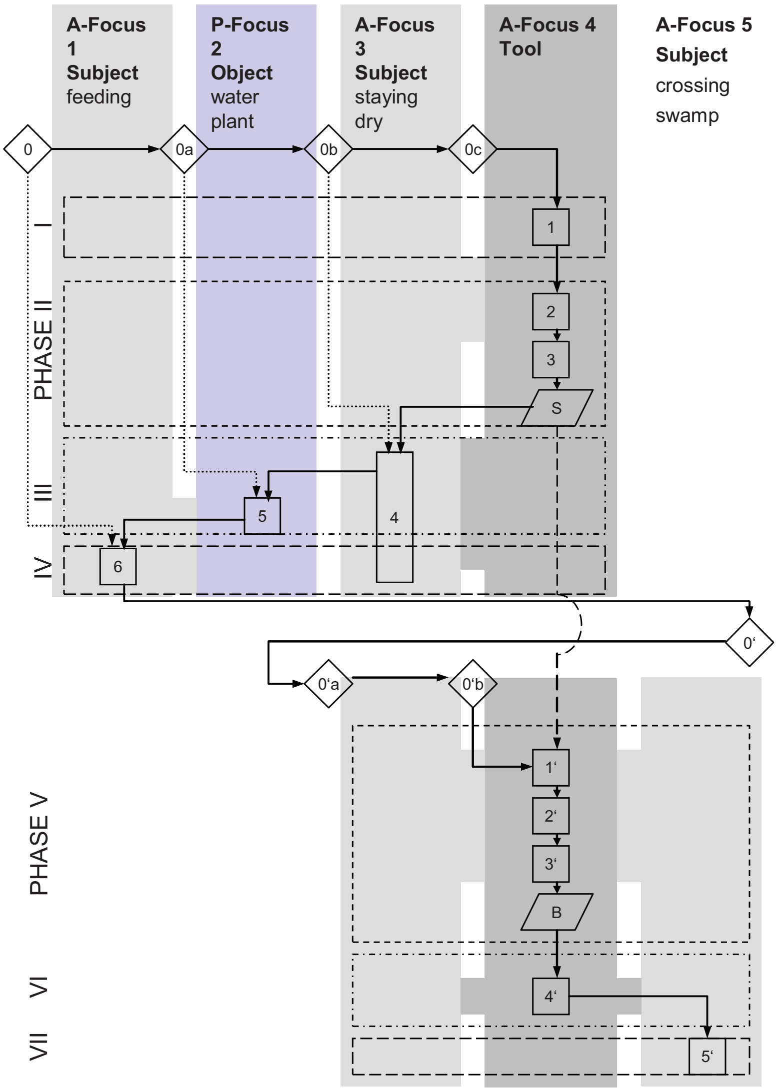


Fig. 44 Cognigram of a western lowland gorilla using a stick for support and then as a bridge.

The impulse for both uses of the tool is the same specific external stimulus, the swamp. In both instances, the solution for the problem is found in the immediate vicinity. In the first thought and action chain, the tool serves a secondary goal (s.a.): The basic need for food is accompanied by the second need to stay clean. This is satisfied through use of the tool (fig. 44). After the action chain in the subsistence context was completed, the basic need to cross the swamp activates a new, intentionally independent thought and action process that, through use of the same stick in another function, is connected to the previous action sequence. The action sequence in the subsistence context is not interpreted as a completed and connected complex. Instead, individual elements are transferred to another context where they are partially altered.

This behavior represents an extension of the problem-solution distance in which an action chain is not static or thought of as a self-contained whole. The solution of a problem is found by reflecting on remembered elements from *other* action contexts. Therefore, a tool can occur in correlation with a number of different foci of attention. In the case of the zebra, the entire action chain was transferred to another context (s.a.); in this case, only one element is transferred and included in another thought and action chain. The flexibility of the tool behavior is increased.

A Neesia Fruit is not an Insect Nest: e.g. Types of Probes

The use of one object in different action contexts requires a certain degree of abstraction of the situation and the tool properties. The same is true when different tools are used in nearly identical contexts. The use of different extraction probes by orangutans in a subsistence context has been well documented from this perspective (Fox et al. 1999).

While the tools - newly torn off, defoliated, shortened and partially decorticated branches - and the thought and action process - production of a tool, food extraction, consuming food - seem identical, the difference between fishing for the seeds of the Neesia fruit and different insects can be found in the details. An inner stimulus starts the search for a nest, a prerequisite to the extraction of insects from the nest. Unless the impulse for the behavior is the accidental discovery of a nest, then the impulse is a specific external stimulus. Only once a nest is found, the orangutan searches nearby for a suitable branch or bush, which it can then use to make the required tool. The behavior involved in the extraction of seeds from a neesia fruit can also be stimulated through either a specific external or an internal stimulus. The probe is produced first. Then the orangutan climbs the fruit tree or chooses the fruit, from which it will extract the seeds by first removing the spiny hairs that surround the seeds (fig. 45).

Probes for extraction of a) insects / honey b) neesia fruits by *Pongo pygmaeus* (after Fox et al. 1999)

a)

0. Perception basic need: eating insects / honey
0a. Perception subproblem 1: need of a nest

PHASE I: Search for an insect nest

1. Searching and finding a nest

0b. Perception subproblem 2: tool for extraction necessary

PHASE II: Search for raw material

2. Search for adequate fresh branch in the vicinity (ca.1 m)

PHASE III: Production of a probe for extraction

3. Breaking of the branch
4. Defoliating
5. Shortening
6. Decorticating

PHASE IV: Extraction of insects / honey

7. Pounding, pocking, probing
8. Extracting

PHASE V: Satisfaction of need

9. Consumption

b)

0. Perception basic need: eating cernels of the neesia fruit
0a. Perception subproblem 1: need of a neesia fruit
0b. Perception subproblem 2: tool for extraction necessary

PHASE I: Search for raw material

1. Search for adequate fresh branch

PHASE II: Production of a probe for extraction

2. Breaking of the branch
3. Defoliating
4. Shortening
5. Decorticating

PHASE III: **Search for a neesia tree**

6. Searching and finding a tree and a fruit / transport probe

PHASE IV: Extracting kernels of the neesia fruit

7. Removing spiny hairs from the cracks of the fruit
8. Pushing the kernels towards the open top of the fruit

PHASE V: Satisfaction of need

9. Consumption

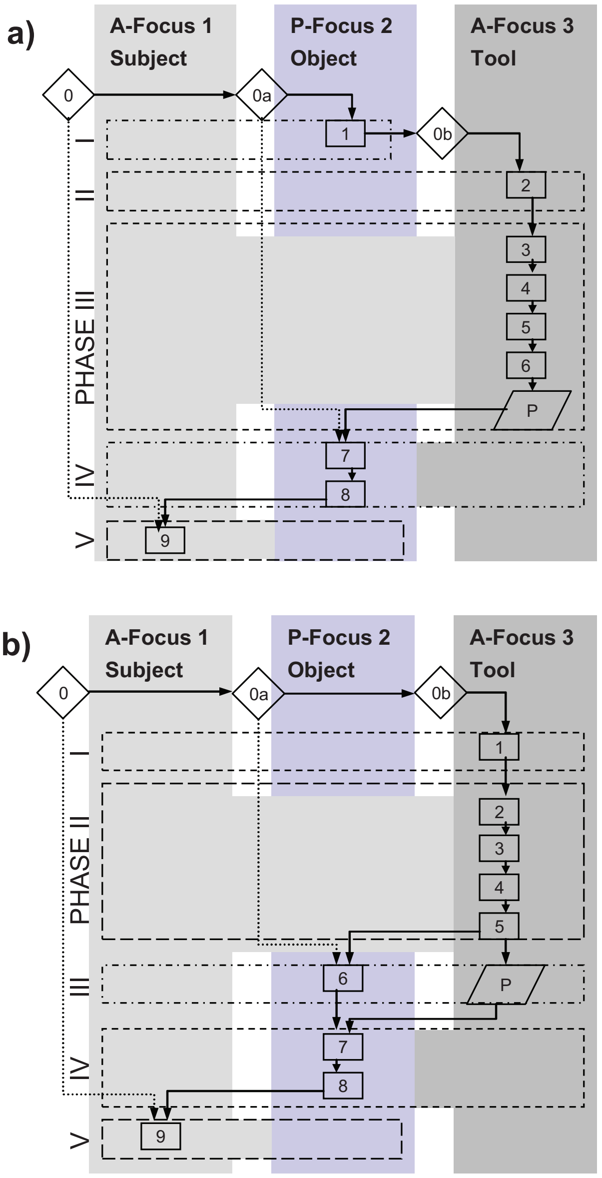


Fig. 45 Cognigram of the use of different probes by Orangutans.

In the case of the insect probe, the tool focus is only activated once the target object is found. This does not reflect a lack of anticipatory thinking, but is ecological and at the same time economically smart. Even when an animal actively searches for an insect nest and doesn't simply find one per accident, it is more efficient to activate the tool focus afterwards since the tool type depends on the type of insects to be extracted or insect nest that needs to be opened. Among the orangutans on Sumatra, Fox et al. (1999, 104) observed significant difference in the type of probe made out of new twigs dependent on the target object. The probe for ant nests are thin and usually decorticated, for spineless bees they are of medium thickness are less frequently decorticated, while the tools for termites are thick and rarely decorticated. The tool form is clear for the extraction of seeds from the neesia fruit. The tool form can be anticipated and the tool produced early – possibly using better raw material resources than those found on site in the neesia tree. If we only recognized the search for insects by orangutans and ignored the ecological and economical conditions of the action chain, then we would get a false impression of this animal's maximum possible problem-solution distance. It is only possible to recognize a minimum of the actual possible cognitive fitness.

Fig. 46 A New Caledonian crow (*Corvus moneduloides*) with a hooked probe (courtesy of Gavin Hunt).

While probes used by orangutans (Fox et al. 1999) and chimpanzees (Hicks et al. 2005) or the perforation of different types of bee nests, also by chimpanzees (Stanford et al. 2000) look very similar and the transitions are smooth so that the differentiation between the tool groups can only take place using statistical methods, the New Caledonian crow (*Corvus moneduloides*) uses two phenomenological different types of tools as probes (Hunt 1996, 2000; Hunt & Gray 2003, 2004; Hunt et al. 2001). The mode of production for these two tool types, probably used to search for insects in dead and living wood, is very different. The production of hooked probes made out of branches (fig. 46), which are used throughout a large area in the southeast of the New Caledonian island Grand Terre, begins with the selection of a suitable forked branch. A branch is broken off above the fork, then the remaining branches beneath the fork are removed and the probe is defoliated and decorticated. Finally, the hook is formed by removing small pieces of wood. In the observed cases, the production of the probe takes on average 68 ± 12 s (Hunt & Gray 2004).

Hook-Probe (a) and stepped Pandanus-Probe (b)
by *Corvus moneduloides*
(after Hunt & Gray 2004 (a) and Hunt & Gray 2003 (b))

a)
0. Perception basic need: food
0a. Perception subproblem 1: need of insects
0b. Perception subproblem 2: extraction tool necessary

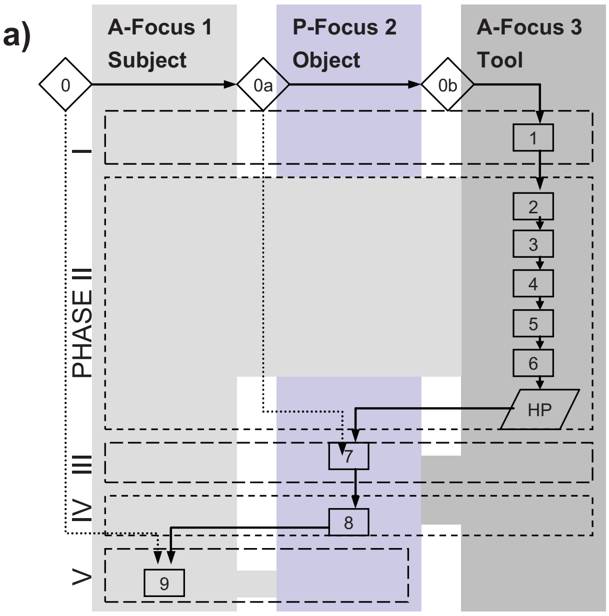
PHASE I: Search for raw material
1. Search for suitable fresh forked branch

PHASE II: Production of Hook-Probe
2. Breaking off a branch above the fork
3. Breaking off branch directly under the fork
4. Shortening the branch
5. Trimming off side-branches
6. Finishing of the hook end

PHASE III: Search for insect holes
7. Search for insect holes in wood / transport probe

PHASE IV: Probing
8. Probing / extracting the insects

PHASE V: Satisfaction of need
9. Consumption



b)
0. Perception basic need: food
0a. Perception subproblem 1: need of insects
0b. Perception subproblem 2: extraction tool necessary

PHASE I: Search for raw material
1. Search for a suitable fresh Pandanus leaf

PHASE II: Production of Pandanus Probe
2. Ripping across
3. Ripping longitudinal
4. Tearing off

PHASE III: Search for insect holes
5. Search for insect holes in wood / transport probe

PHASE IV: Probing
6. Probing / extracting the insects

PHASE V: Satisfaction of need
7. Consumption

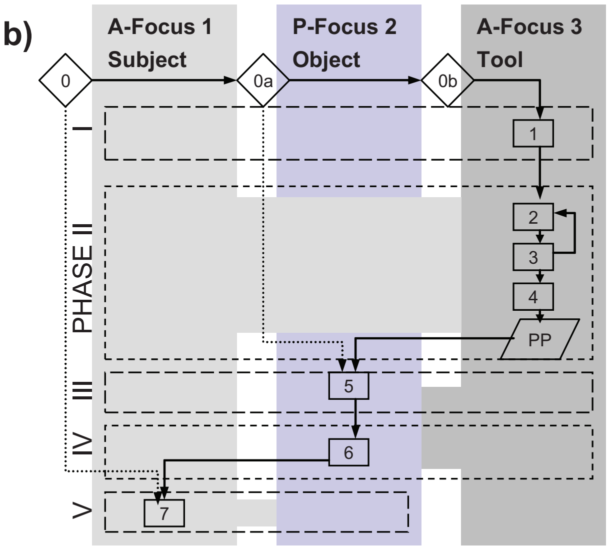


Fig. 47 Cognigram for New Caledonian crows using different types of probes.

Tiered probes made out of segments of Pandanus leaves, which have natural barbs, are produced using different techniques (Hunt & Gray 2004; Hunt et al. 2001). The crows tear a leaf with their beak and pull the segment away from the stem. They tear the leaf perpendicular to the original and then tear the segment off along the direction of the plant fibers to separate a suitably long probe. The object is generally not modified further after it has been torn off (Hunt 2000). Both types of tools are used numerous times at different locations for up to 30 minutes at a time to probe for food; they only put down the probes on the branches on which they sit for short periods of time (Hunt 1996) The impulse for both types of tool use – specific the external stimulus or general external trigger or internal stimuli – remains unclear.

Although the production methods of both tool types are very different, their cognigrams are very similar (fig. 47). Starting with the basic need for “food”, the same secondary problems are recognized and two further foci of attention for the insects and their nests and the extraction tool are activated, next to the subject focus. The search for a suitable tool and the manipulation of that tool take place within the tool focus and are followed by an extraction and a consumption phase. Deviation in the thought and action chain can only be found in the production of the tool: In the case of the hooked probe, this phase includes various different steps, while the production of a leaf probe repeats the same steps, tearing and tearing off. The problem solution distance of both thought and action chains is identical.

Hunt und Gray (2004, Fig. 2) separate their *chaîne opératoire* for the production of the hooked probe into four different phases - selection of the forked branch, separation of the extra branches above the fork, separation of the tool below the fork, fine tuning of the hook. According to the definition of a phase as the combination of closely related individual actions that lead to an intermediate result, which cannot be interrupted and then resumed at the same place some time later, but has to be started over from the beginning of the sequence, the New Caledonian crow’s behavior represents a process consisting of one phase. It would only be possible to interpret a second phase after the separation of the tool, if a bird were to fly away with an incomplete hooked branch (ibid. p. 89); however, a resumption of tool production has not yet been observed.

We can observe different local variants within the group of pandanus leaf probes: steppes, long and thin and short and wide probes, their distribution partially overlaps (Hunt & Gray 2003) (Abb. 48). The basic production technique of tearing into the leaf and then tearing it off lengthwise is the same in all three variants. The variants can be attributed to slight differences and preferences in the production techniques. At this time, it is not clear what is being extracted with which tool type. Therefore it remains unclear whether the crows, like the orangutans, produce tools suited to a specific problem, whether individual animals create and use different variants (hooked branch and Pandanus probes, different Pandanus leaf probe versions) or whether an animal leans and implements only one variant of the probing behavior throughout its life. Examinations of naïve juvenile crows, brought up in captivity, show that the probing behavior is innate; the behavior variant that is actually implemented is learned (Kenward et al. 2005). It is possible that the tool behavior of *Corvus moneduloides* (comp. Chapter 17) in a subsistence context is not as flexible and abstract as it first appears.

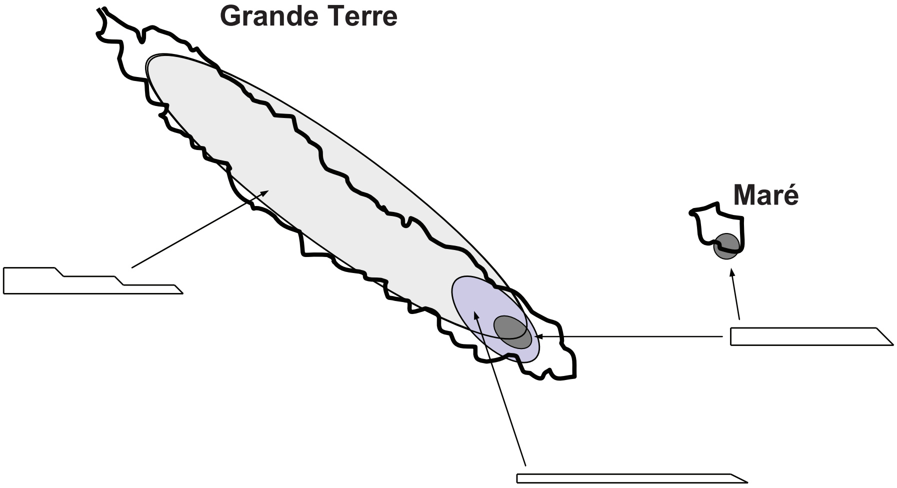


Fig. 48 Distribution of different versions of Pandanus leaf probes manufactured by New Caledonian crows (after Hunt & Gray 2003, fig. 2)

One Tool for Multiple Subjects: e.g. Playing Catch

A context of tool use that is practically not traceable in an archaeological context is the social context involving games and play. Therefore it is all the more interesting to be able to interpret an observation of this behavior in great apes with respect to the action chain and problem-solution distance. Ellen Ingmanson (1996) reports solitary play with different objects as well as social play among bonobos. Play with objects begins at the age of ca. three months; it is primarily solitary until the age of two years and occurs only in a social context after the age of three years. In this case, a thing is not the object of the game (comp. Chapter 17) but also an object that acts as a medium to initiate play and function as an indicator of play.

When playing catch, a stick indicates which animal is “it” to be caught. The purpose is not to get the stick because if the individual being chased drops the stick, the individual chasing it stops and waits until the medium is picked up again before the chase can continue. If an individual throws the stick away, e.g. when the group moves on, the game ends. The game with the stick as medium, a common focus, seems to take longer and occur more frequently than the game without a tool: *„…the stick enhances to play, signaling to other players information and focusing attention on the activity itself. “* (Ingmanson, 1996, 201)

The interpretation of the tool behavior in a Cognigram is based on a number of assumptions for which the description remains unclear. The indicators for the start of the game remain vague: Do the players gather together, does an individual initiates the game after finding a suitable stick, or is the suitable stick a specific external trigger that starts the game? Figure 49 shows the cognigram in which the players gather first and the tool is brought into the process at a later point in time, the reverse is also possible. As a consequence, phases I and II would be reversed when the subject acts on an inner stimulus and searches for the stick first. If a conspicuous stick is needed to initiate the idea of the game, then the number of phases in the action chain would be reduced by one. The further order of events and the problem-solution distance would not change; the communication of the wish to play could possibly be simplified. To improve the legibility of the following cognigram, I only included one additional player.

In contrast to the previous examples, alongside the original subject focus, a new subject focus is activated for each additional player. In tool behavior with a higher purpose, other individuals are understood to be subjects with their own needs but are *treated* as, at best, responsive objects. In the example of bonobos playing catch, other players function as independent acting subjects. The cognigram, which follows the existing principles, greatly simplifies the event: The cognigram should consist of two individual and interlocking sub-action sequences for a minimum of two individuals, where each player is treated as a tool together with the object to satisfy the need and as the acting subject. In this case, the tool i.e. the stick only functions psychologically. The long action sequence of the regulated game requires a high degree of flexibility of the subjects since the individual players can influence the satisfaction of their own need, but are not completely in control of it. The stick helps to restrict the required flexibility by focusing the actions on a common goal, satisfaction of a need through play with rules. This tool characteristic is exemplified at the point in the game where the subject drops the game indicator (fig. 49, step 7). The stick on the ground stops the players from continuing according to their original impulse, to catch the subject. The other players stop chasing the subject until it has picked up the stick and continues to run.

The extension of the problem-solution distance in this case, is due to the inclusion of (at least) one other active and independently acting focus of attention, the other player, which the subject attempts to influence with the help of the tool. While action sequences with passive objects as well as active tool foci, still dependent on the subject, can be anticipated and planned, the course of the game itself is influenced by the decisions of two or more subjects. The tool becomes effective during critical points in the action sequence. In the cognigram, these are marked with red arrows. When it is dropped, two different actions are initiated simultaneously: The subject searches for the stick and picks it up again while the other players pause and only recommences the chase when the subject begins to run again. Another critical point is activated when the subject is caught. All players now pursue a different goal: The animal being chased now becomes a chaser; the chaser is now the one being chased.

Playing catch by *Pan paniscus* (after Ingmanson 1996)

0. Perception basic need A:
social play → catching
0a. Perception subproblem 1: willing
conspecifics necessary

PHASE I: Finding a group of players
1. Finding of other players

0b. Perception subproblem 2: indicator
of play necessary

PHASE II: Finding tool
2. Subject 1 searches stick

PHASE III: Playing 1
3. Subject 1 picks up stick
4. Subject 1 runs away
5. Playmate chases subject 1

PHASE IV: Interruption
6. Subject 1 drops stick
7. Playmate pauses and waits

PHASE V: Catching the player holding the stick
8. Subject 2 catches subject 1

PHASE VI: Satisfaction of need
9. Amusement in social play

PHASE III': Playing 2
3'. Subject 2 picks up stick
4'. Subject 2 runs away
5'. Subject 1 chases subject 2

PHASE VI': Satisfaction of need
9'. Amusement in social play

0'. Perception basic need B

PHASE VII: Ending game
10. Stick is thrown away

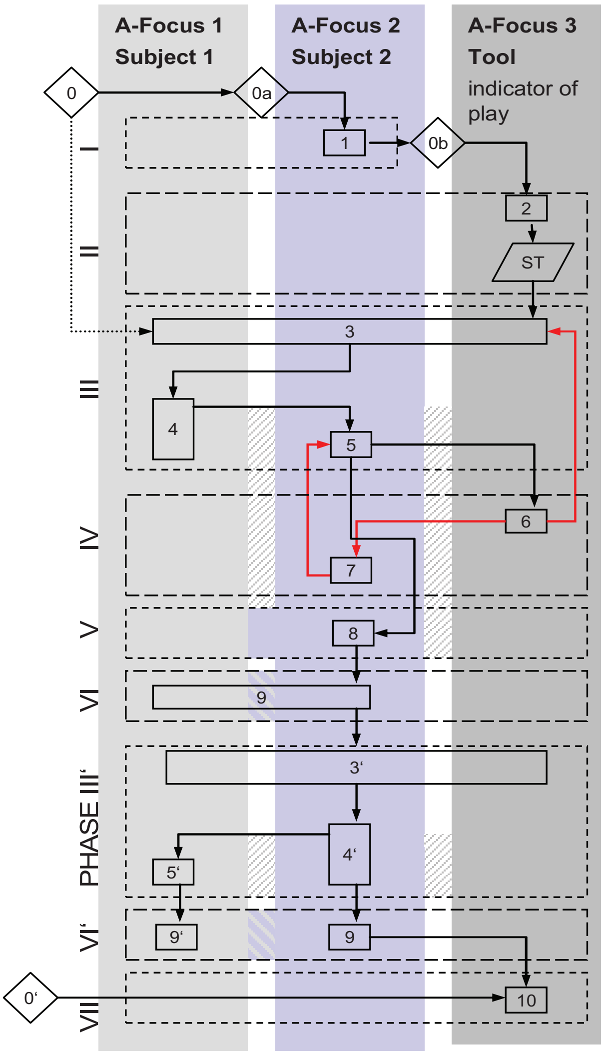


Fig. 49 Cognigram of bonobos using a stick as an indicator in a game of catch.

A Complete Toolbox: e.g. Extraction Sets

Several species of mammals, such as sea otters, orangutans and chimpanzees, have access to a type of toolbox with different tools for different tasks and contexts. These are not used spontaneously but regularly by the group and therefore belong to an established tool inventory. The use of different tools for different tasks in an action chain has so far only been observed among chimpanzees. Sanz, Morgan and Gulick (2004) documented two tool sets used for the extraction of termites from subterranean nests or from aboveground hills used by the Moto group (*Pan troglodytes troglodytes*) in the Goualougo Triangle of the Nouabalé-Ndoki National Park in the Republic of the Congo (fig. 50).

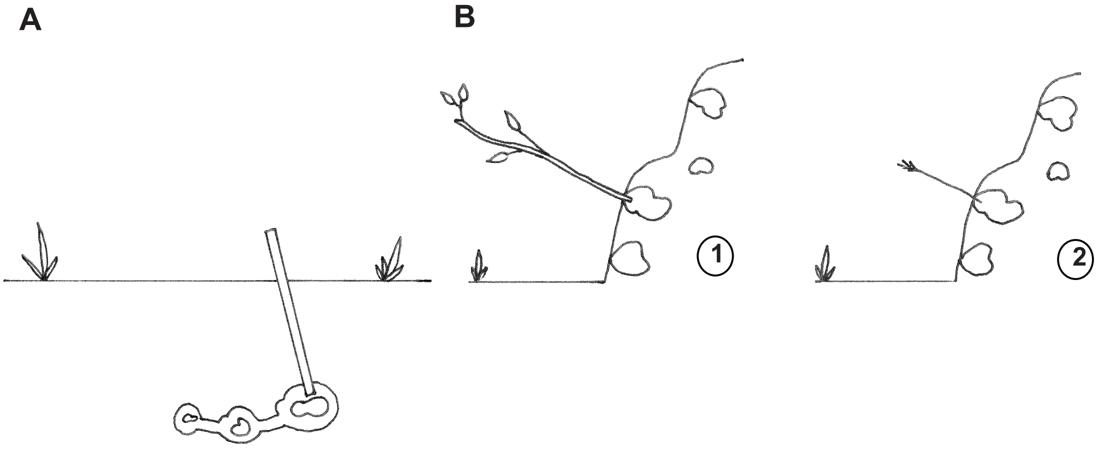


Fig. 50 The use of different tool sets for the extraction of termites from a) underground nests and b) aboveground hills by chimpanzees of the Moto group (drawings by Regine Stolarczyk after Sanz et al. 2004)

To access the underground nests without visible entrances, the apes use heavy sticks to perforate the nests as well as probes to fish the termites out of the opened chambers. The prepared extraction probe – shortened, defoliated, one end chewed with the teeth to form a brush – is commonly kept and carried while the stick for perforating the nests is only kept in one third of the cases. Sticks left over from previous events were frequently used again. The perforation tool is pressed into the earth with both hands, and sometimes also a foot, using the animals own bodyweight. Once the desired depth is reached, the animal pulls the instrument out and inspects it. If the termite chamber is open, the second tool, the probe is activated. Otherwise the perforation process is repeated. In contrast to the underground nests, the aboveground nests have visible entrances, which the termites seal shut when they are not in use. To open these relatively soft seals, the animals use thin twigs as perforation tools. The tool is held with the precision grasp between thumb and second finger. After the entrance is opened and cleaned, the previously produced and used brush probe is used to fish for the termites. It is possible that chimpanzees (*Pan troglodytes troglodytes*) in the Ngotto Forest in the Central African Republic use similar perforation and extraction sets for dipping ants and harvesting honey (Hicks et al. 2005).

Use of a tool set to extract termites by *Pan troglodytes*
(after Sanz et al. 2004)

0. Perception of basic need: food
0a. Perception subproblem 1: open termite nest / extract termites
0b. Perception subproblem 2: tool necessary to open nest
0c. Perception subproblem 3: tool necessary for probing

PHASE I: Manufacture of probe I
1. Search for appropriate twig

PHASE II: Manufacture of probe II
2. Detaching the twig
3. Shortening / removal of leaves / fraying of brushtip

PHASE III: Transport of probe
4. Transport of probe to termite nest

PHASE IV: Search for chisel
5. Selection of chisel on site

PHASE V: Opening the termite nest
6. Pushing with chisel (several times)
7. Inspection of chisel

PHASE VI: Probing for termites
8. Extraction of termites with probe

PHASE VII: Satisfaction of need
9. Consumption

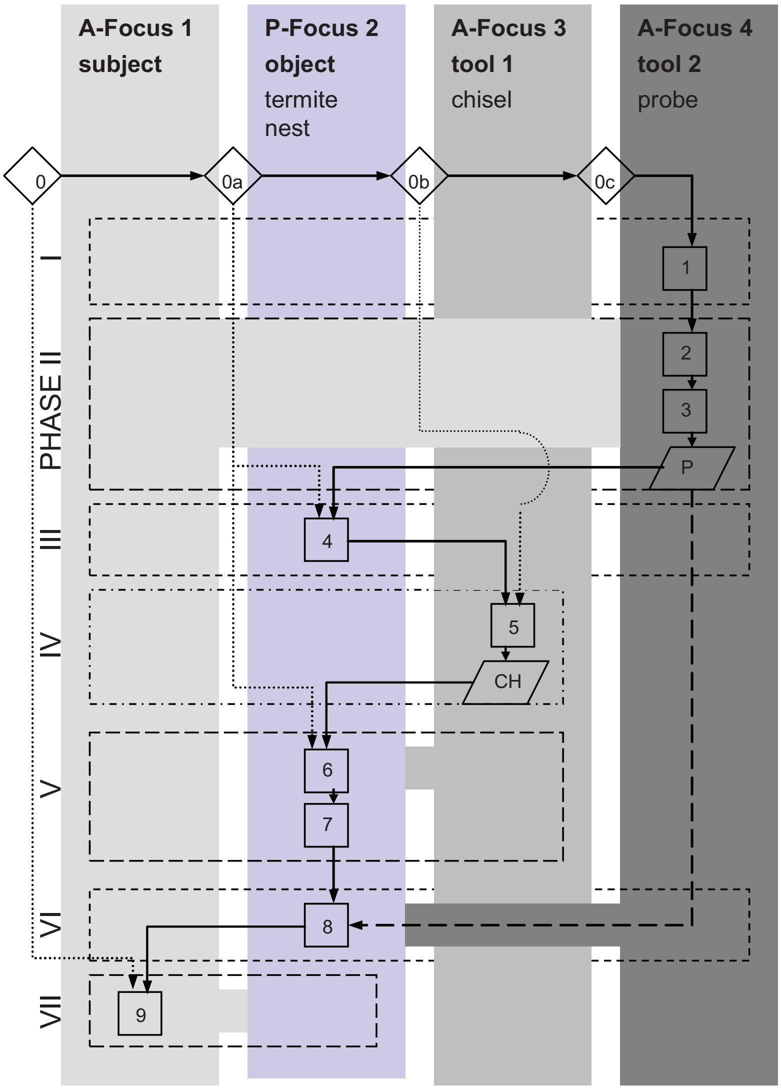


Fig. 51 Cognigram for chimpanzees using different tools to extract termites from their nests.

The thought and action chains for both extraction sets observed by Sanz et al. (2004) are identical except for some details (Fig. 51). The trigger – specific external stimulus or general external or internal stimuli – is not clear. In both cases, two tool foci are activated in parallel at the beginning of the process, together with the subject and object foci. Bringing both tools to the termite hill is proof that the animal had the foresight to recognize the need for both action components, perforation and extraction. We already identified four parallel active foci of attention in the example of nose protection by dolphins and the support branch used when harvesting water plants by the western lowlands gorilla, however, two of these were sub-foci of the same individual, the active subject. In this case, for the first time, an individual uses three external objects in parallel in a single action phase. This fact and the anticipation of different action elements represent a significant expansion of the problem-solution distance.

Aside from using different tools to perforate and extract food from ant and termite nests, Sugiyama (1997) also reports that the animals also used leaf sponges and sticks to pull the sponge, soaked with water, out of the knot-hole of a branch (comp. Chapter 19). Although this example clearly shows the conscious use of two different objects by one subject in a thought and action chain, the other examples presented by Sugiyama do not show true *tool-sets*. In the example of the palm crowns, the subject used a stick as a tool to beat the palm crowns to a pulp, afterwards the fibers, soaked full with palm juice, are sucked dry. This does not represent tool use since the fibers are not used or controlled intentionally. Cracking nuts with a hammer and anvil is also not considered to be the use of a tool set since the anvil is only a proto-tool. The same goes for the use of wedges to stabilize an anvil (comp. Chapter 19). Probing into a nut that has already been opened in order to extract the stuck nut requires the use of a tool set – that is, only if the extraction of the nut is attempted by the same animal that cracked the nut.

Fox et al. (1999) also observed orangutans on Sumatra using multiple tools during one extraction episode. They doubt whether the use of „*four tools in succession to obtain honey from a single tree*" (ibid, 105) really represent different tools adapted to the different steps of the extraction process as is the case for the extraction sets used by the chimpanzees of the Moto group; the observation data for orangutans is too scarce for such a statement.

With regard to the problem solution distance, it is important to differentiate whether the additional tool is recognized parallel to a necessary tool already in use or whether its necessity is only recognized after the original tool was used. Besides the subject focus, are only two foci of attention required or three? Earlier examples showed that orangutans and chimpanzees are able to recognize different tools for different tasks and that they are principally able to differentiate a sequence of different tools adapted to the various steps in the process. But are they able to recognize the necessity of different tools at the beginning of an action chain or do they only recognize the need for a new medium when the tool they are currently using doesn't help them anymore?

Stella Brewer and William McGrew (1990) recount the case of a female chimpanzee (*Pan troglodytes verus*): After an unsuccessful attempt to extract honey using a simple probe, she used four different types of tools to open the nest and then probe for the honey. In terms of Fox et al. (1999), different tools are used, each adapted to further advance the action chain: First, a strong chisel, then a second thinner and shorter chisel, followed by a thin awl to open the nest and, finally, multiple similar probes with which honey is extracted for circa 10 minutes. It remains unclear from the observations whether the animal really foresaw the need for four different tools and thereby activated a total of five foci of attention in parallel for each tool type and the nest.

A simpler cognigram with the same result is also possible (fig. 52). After the first effort failed and ended without satisfaction of the basic need, the same basic need “eat honey” as well as the same sub-problem “open nest” are recognized anew and a new variant of the second sub-problem “need tool” is activated: a different tool. Twice more the application of the new tools ends without the nest being opened; the activated action chain is broken off (Step 7’ and 7’’). A new action begins with the repeated perception of the first sub-problem and the sub-problem variants 2'' and 2'''. The animal is finally able to open the nest using the awl, there is no frustration, instead the need for an additional tool, the probe, is recognized (sub-problem 2’’’’). The use of this tool finally leads to the satisfaction of the basic need.

In place of elements in a complete and anticipated action chain with five parallel and active external foci of attention, the production and use of different tools represents multiple, successive action chains with an identical goal. Each phase I-I’’’, II-II’’’ and III-III’’’ is activated through a renewed observation of the object “insect nest” and a new focus of the following action sequence. At most, it is possible that the need for a probe is anticipated as in the extraction set of the Moto group (s.a. Sanz et al. 2004). Each of the short action sequences between the chisel and the awl could have had different consequences. The current result could have required the use of an additional tool or the action could have ended with success instead of frustration, leading to the direct activation of the probe. Although the animals have different tools adapted to different requirements available to them in the form of mental templates, the necessity for using each of these individual tools is not foreseen (parallel perception), but dependent on the result of the previous action chain (consecutive perception).

Use of different tools to extract honey by *Pan troglodytes*

(after Brewer & McGrew 1990)

0. Perception basic need: (honey) food
0a. Perception subproblem 1: open nest / extracting honey
0b. Perception subproblem 2: tool necessary

PHASE I: Search for raw material probe 1
1. Search for raw material

PHASE II: Production probe 1
2. Breaking off a green branch
3. Modification

PHASE III: Use of probe 1
4. Repeated probing (unsuccessfully)
5. Discarding probe 1

PHASE IV: Satisfaction of need
6. Not successful: Frustration

---

0. Perception basic need: (honey) food
0a. Perception subproblem 1
0b‘-0b‘“. Perception subproblem 2‘-2‘“: different tool necessary

PHASE I‘- I‘“: Search for raw material chisel 1 / chisel 2 / awl
1‘-1‘“. Search for raw material

PHASE II: Production of chisel 1 / chisel 2 / awl
2‘-2‘“. Breaking off a branch
3‘-3‘“. Modification

PHASE III‘-III‘“: Use of chisel 1 / chisel 2 / awl
4‘-4‘“. Repeated pounding
5“-5‘“. Inspection of tool
6‘“. Probing
7‘-7‘“. Discarding tool

PHASE IV‘-IV“: Satisfaction need
8‘-8“. Not successful: Frustration

0b““. Perception subproblem 2““: different tool necessary

PHASE V““: Search for raw material
9““. Search for raw material probe 2ff

PHASE VI““: Production of probe 2ff
10““. Breaking off green twine
11““. Modification

PHASE VII““: Use of probe 2ff (10 min)
12““. Probing

PHASE VIII““: Satisfaction of need
13““. Licking off honey

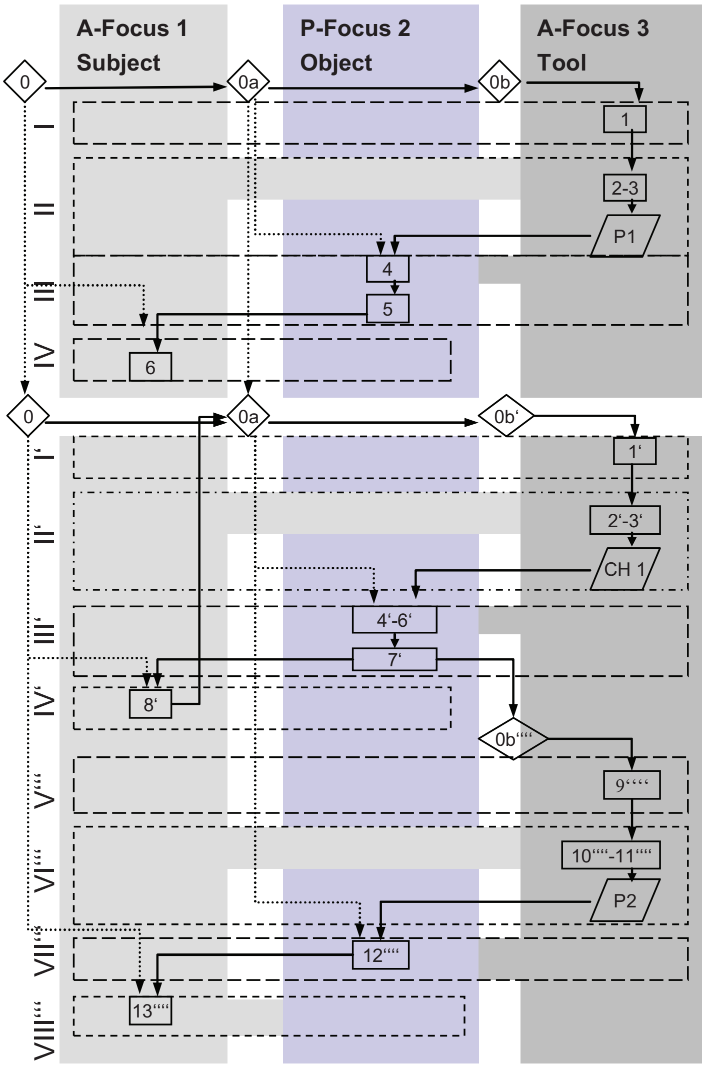


Fig. 52 Cognigram of the use of different tools by chimpanzees to extract honey.

Even though the behavior observed by Brewer and McGrew (1990) does not consist of a complete and anticipated long action chain but of a sequence of shorter chains, it is still remarkable from the point of view of the problem-solution distance due to the link of multiple chains of operation to reach a specific goal. The actual distance from the subject cannot be determined, however, it is not discouraged of its goal neither through the first failed attempt nor through the small advances using the chisel, although also without success. Frustration at the end of an action chain does not cause the chimpanzees to give up on their problem; instead they continue to purse the solution to a problem that seems solvable even though there were setbacks.

Variations and Limits

The examples in this chapter were selected to give an overview of the different types of problem-solution distances in animal tool behavior and to clarify their limits. This compilation is not representative because it does not show the frequency of the behavioral forms, nor is it differentiated according to animal species or animal groups. This type of notation shows how variable animal tool behavior can be from a cognitive perspective and in how many different contexts and forms it can occur. The itemization of behavior into Cognigrams clarifies the differences between proto and true tool behavior with respect to the active effect of media and the control over them. The interpretations of the cognitive foundation of behavior seem to be strongly dependent on the subject's insinuated intentions. The categorization as tool behavior of certain actions is doubtful or cannot be confirmed.

Aside from common tool use – the use of an active and controlled external medium on an object or the acting subject, where a minimum of two foci of attention, the subject and the tool, and possibly another passive attention focus for an object on which the subject or tool will act, are active - animals also demonstrate more complex tool behavior. With the help of partially manufactured tools, basic needs are satisfied and subordinate problems are solved in a secondary action. At the same time, other subjects and the other subject's problems are recognized and the tools are used to reach a solution. Whether this represents the recognition of the other animal's basic need, if the behavior is based on a mental theory - the assumption of an equally active mind in the other individual - or whether the acting subject assimilates the other animal's body and needs and thereby satisfies its own wishes, e.g., bodily hygiene, remains unclear. In animal tool behavior, two additional active foci of attention can be active parallel to the subject focus: While during the game of catch among bonobos the subject only controls one additional active focus, the chimpanzees using their extraction sets draw on two different tools when planning the solution to their problem, although only one tool is used at a time.

The coding of animal tool behavior into cognigrams shows that the problem-solution distance is not a one-dimensional measurement but encompassed different axes:

a) The number of steps involved in an action: This element is also documented by *chaînes opératoires* in their common format and illustrates the length of a solution process.

b) The number of phases in the action process: This element is critical for the problem-solution distance because the phases comprise stages of the process with sub-goals and intermediate results. The phases are parts of a thought and action chain that, with sufficient abilities to abstract, become subroutines that can be implemented in other actions. Thinking in phases represents a hierarchization of the problem-solution path. A simple thought and action chain for tool behavior in which it is not necessary to search for an object because it is not required in order to satisfy the basic need or is already available as a specific external stimulus, consists of three action phases: the search and use of the tool and finally the satisfaction of the need. If an additional object needs to be found or produced to satisfy the need, e.g. a fruit, then the problem-solution distance is expanded by additional phases. Tool behavior consisting of five or more phases is limited to chimpanzees, bonobos and humans, according to current observations. Among the different species of gorilla and orangutan, it is not the cognitive framework that is missing; it is probably a lack of observation of these behaviors. Due to their ability to flexibly integrate known subroutines into other action chains, it is possible to postulate conscious hierarchical thinking in phases for the great apes. The sequence of phases in a thought and action chain is also only briefly interrupted for these animals.

c) The total number of active and passive foci of attention: Passive elements are variables in the action to which the active factors need to be adapted to reach the desired results. The content of the passive foci of attention can be selected at the start of an action; afterwards, they are fixed and can only be influenced through the changing and controlled effects of the content of the active foci. During the non- or proto-tool behavior, generally only one active attention focus is opened at one time; with in true tool behavior, the effects of at least two agent or factors – subject and tool – have to be controlled. In animal tool behavior, a maximum of four foci of attention, three active foci, were observed in an action chain. Even when three agents are involved such as in the game of catch among the bonobos or the chimpanzee's extraction sets, only two are controlled at a time.

d) The number of active and passive foci of attention whose contents are processed in a phase: While the total number of attention foci includes all passive variables and active factors anticipated in an action, the number of activated foci in a phase shows which variables and factors the subject focuses on in the current action phase. Hiding the foci that are not active in the current phase is an advantage when there are a number of foci, by simplifying the cognitive complexity of individual action phases This effect is not pronounced among animals due to the small number of foci; the differentiation between the total number of foci and the number of steps active in a phase is relatively insignificant.

e) The number of foci of attention affecting each other: The contents of active foci of attention can affect passive variables as well as active factors. When one active element influences another active element, a functional chain is created. Each action chain, even those with simple tool production, includes a functional chain: The subject changes the tool which in turn affects the object or the subject. In a functional chain, the following effects are dependent on each other. In animal tool behavior, the number of foci of attention affecting each other is limited to three, according to current observations. In behavioral forms with multiple tools such as the chimpanzees' extraction set the tools don’t affect each other; therefore these also include a functional chain with three elements.

In this chapter, I focused on the spectrum of problem-solution distances among animal tool behaviors; these results will be compared to examples of human tool behavior from different episodes of development.

19 Problem-Solution Distances in Human Tool Behavior

Similarly to the analyses of the problem-solution distances in animal tool use, these can also only be exemplified for human tool behavior. The examples were selected from 2.5 million years of archaeological tool traditions based on their informational value for the expansion of the problem-solution distance. Tools that represent pivot points in cognitive development such as the first flaked tools of the Oldowan, handaxes or Upper Paleolithic blades are analyzed for their expansion potential. These are compared to other, from the point of view of cognitive development less relevant, tools such as the bone tools from Swartkrans, the spears from Schöningen and more complex devices. This selection of nearly chronological examples does not imply that no further expansion of the problem-solution distance took place between the first occurrence of the individual examples and the appearance of synthetic raw materials. The selected examples cannot represent a complete picture of the development of this aspect of human cognition due in part to the fragmented nature of archeological traditions. They serve to present an overview in order to understand and discuss the nature of the development process.

Multiple Tool Elements Together: From Stacking Boxes to Assembling a Fishing Rod

In the previous chapter, I introduced the use of two different tools within one action sequence. This behavior counts as some of the most complex tool behavior observed among non-human primates. The anticipation of different tools to find a solution to the problem became apparent for the termite extraction sets among the chimpanzees of the Moto group (Sanz et al. 2004). This foresight has been assumed but not proven for similar behavior among other groups of chimpanzees (Brewer & McGrew 1990; Hicks et al.2005) and orangutans (Fox et al. 1999). However, it is important to differentiate between the succession of different tools in different phases of an action sequence and the use of two tools within a single phase. Experiments with primates have shown that chimpanzees, orangutans and western lowland gorillas can principally combine multiple elements into one tool in order to achieve an objective.

Fig. 53 A chimpanzee trying to reach a reward with the help of stacked boxes (from Köhler 1963).

Chimpanzees can stack up to four boxes and use them as a ladder to try and reach objects that are otherwise out of their reach (Fig. 53). In different tests, the animals even emptied and carried the boxes, whereby up to three individuals were observed cooperating together (Köhler 1963; Yerkes & Learned 1925; Bingham 1929, Schiller 1957, Yerkes 1943, Wazuro in Döhl 1966, Lorenz in McGrew et al. 1975, von ButtelReepen in Bierens de Haan 1931 in Beck 1980, 97-98). Gorillas (Yerkes 1927a, 1927b, 1928-29 in Beck 1980, 78) and orangutans (Lethmate 1976 c, 1976d, 1977a, 1977b, Yerkes 1916 in Beck 1980, 74) are also able to stack up to four boxes on top of each other to reach a reward. Orangutans also place chairs on top of tables simply to climb and play on them (Rensenbrink 1960 in Beck 1980, 74). This behavior clearly represents a complex problem solution using objects; whether the boxes can be accepted as tools is subject to interpretation. On the one hand, the boxes are freely movable and are arranged spatially to achieve an objective, however, during the phase in which they are climbed, they are not manipulated freely: Beck (1980, 10) defines this behavior as tool behavior. According to the definition by Baber (2003, comp. Chapter 14), the boxes are not considered as tools.

From the point of view of the problem-solution distance, do the boxes used for stacking represent one or more active or passive foci of attention? When the animal climbs up the boxes, these are not anchored to the floor. The subject must control the effect of the boxes, therefore they must be considered as active foci. However, the subject does not have to manage multiple tools that act upon each other in separate foci, in order to reach its reward, it controls all boxes together as one tool in one attention focus (Fig. 54).

Creation of a ladder using stacked boxes and its use by *Pan troglodytes* (after Beck 1980)

0. Perception basic need: food
0a. Perception subproblem 1: getting fruit
0b. Perception subproblem 2: tool (ladder) necessary

PHASE I-I“‘: Search for raw material
1.-1“‘. Search for adequate box 1-4

PHASE II-II“‘: Transport of raw material
2.-2“‘. Transport of box 1-4

PHASE II: Production tool
3.-3“‘. Stacking of boxes 1-4

PHASE IV: Use of tool
4. Climbing on the stacked boxes
5. Picking the fruit

PHASE V: Satisfaction of need
6. Consumption

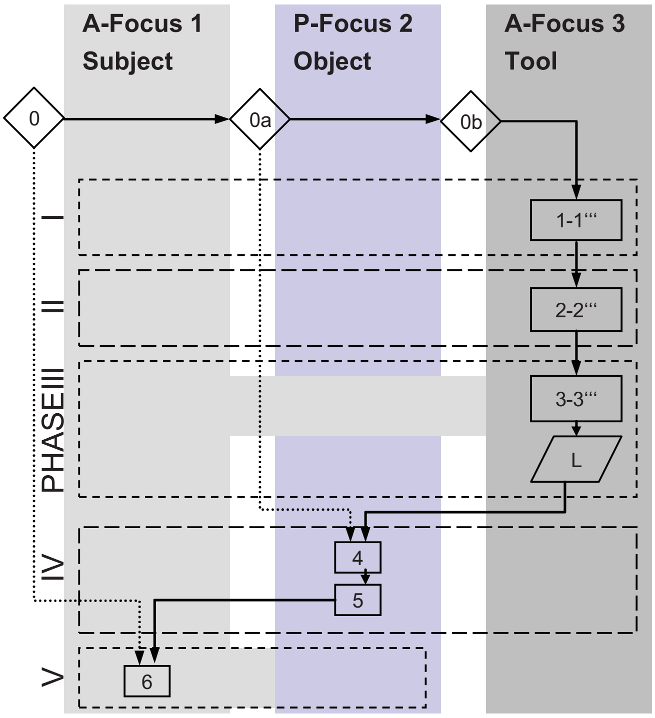


Fig. 54 Cognigram of the creation of a ladder using stacked boxes.

The addition of elements to produce a tool is only a different method of assembly similar to subductive manipulation - removing pieces through defoliation, decortication or trimming side branches etc. This technique provides new possibilities to finding solutions, but it does not represent an additional expansion of the problem-solution distance compared to the subductive and transforming alteration of a raw form presented in Chapter 18 (comp. Fig 39). A similar combination of tool elements, combining up to three staffs, was observed in another experiment involving chimpanzees (Köhler 1963; Kats 1972b, Schiller 1957 in Beck 1980, 114) (Fig. 55). In similar experiments, orangutans have combined up to five sticks (Ellis 1975, Lethmate 1976b, 1976c, 1976d, 1977a, 1977b, 1977c, 1977d, 1977e, 1978 in Beck 1980, 72 and 110).

Different elements are added together to produce a tool that is handled as one unit with only one focus of attention for the solution of the problem.

Fig. 55 A chimpanzee fitting staffs together to produce a tool with which he can reach a reward that is located out of his reach (from Köhler 1963).

Another combination of tools is involved in the experimental task of using one tool to reach a second tool that was placed out of reach in order to be able to retrieve a reward that could not be reached using the first tool. Different experiments have shown that chimpanzees can use up to four sticks to finally reach the desired object (Köhler 1963; Hobhouse 1926, Jennison 1927, Jackson 1942, Jacobson et al. 1935, Kats 1972b in Beck 1980, 93). At least two different active tool foci and the subject focus are included in the thought and action chain; however, only one is actively controlled in any one phase of the process. The behavior represents a sequence of tool uses, whereby both tools are not targeted on the final reward as in the example of the Moto group's extraction sets (Sanz et al. 2004). The subject uses the first tool with the goal to reach the second tool with which it will then attempt to retrieve the reward. Combining tools in this form represents an expansion of the problem-solution distance, similar to the simple production of tools, with an additional phase in the action chain that is psychologically focused on the target object but whose actions are not aimed directly at it.

A third variation of the combination of tools in one phase was documented by Reuvens (in Yerkes & Yerkes 1929 in Beck 1980, 72): An orangutan threw a sack over an orange located outside of his reach, using a second overlapping sack, he pulled the first sack together with the underlying orange to him. In this case, both tools are used in sequence; only one object is controlled in each individual phase. The first sack alters the target object so that it can be retrieved using the second object. The problem-solution distance is expanded compared to the termite extraction set because the first sack is not cast aside after it was actively used, instead, it is treated as a unit together with the fruit. Whether the orangutan recognized the connections and planned to use both tools in a sequence to reach its rewards does not become clear from the description of the behavior.

The use of multiple similar tool elements together to achieve an objective has so far only been documented among primates in captivity. It represents a preliminary stage to the simultaneous use of different elements with different functions in one phase. This in turn is the basis for the production of tools using tools, which has, so far, only been observed in hominids or has been reconstructed from archaeological remains.

A New Tool Function: Tools to Produce Tools

The production of tools using tools, so-called secondary tool use (Kitahara-Frisch et al. 1987; Kitahara-Frisch 1993; Haidle 1999, 2000, 2004a, 2004b) demonstrates a new tool function that prerequisites the combination of multiple devices in one phase. As stated in the discussion of the differences between cracking nuts by chimpanzees and the production of stone tools (Fig. 19-21) in Chapter 16, the use of a secondary tool represents an expansion of the problem-solution distance, in contrast to the direct production of tools by the subject using hands, mouth, teeth or claws etc. (comp. Chapter 18, Fig. 29) as well as the previously mentioned combination of multiple tools in a phase. For the first time, a medium is not only used to manipulate a target object but to manufacture another medium, which will be used to satisfy a basic need. Thinking-around-the-corner is expanded to include the production of tools.

Three active foci of attention are active in a thought and action chain involving secondary tool use: The subject focus, the focus of a tool used to manipulate an object and the focus of the second tool used to produce the first tool. The active sequence is expanded by the subject's use of a tool to fashion a medium that will finally solve the problem. In contrast, the production and application of a termite hook only has two active foci: The subject manipulates and uses the twig probe to extract termites. In addition, in the production of stone tools all three active foci must be controlled simultaneously and independently of each other within a phase. This differs from previously introduced tool combinations. The core, from which a flake will be separated using the hammer stone, is not just held down in front of the subject, the hammer stone and the core must both be controlled individually to achieve the desired result.

The use of secondary tools such as stone artifacts can be traced back ca. 2.5 million years (comp. Appendix II). Cut marks on animal bones from early Ethiopian find sites such as Bouri (deHeinzelin et al. 1999), Ounda Gona OSG-6 as well as Kada Gona EG-13 and WG-9

(Domínguez-Rodrigo et al. 2005) document that stone tools have been used as cutting tools to disarticulate animal cadavers. Analyses by Mercader et al (2002) prove that stone tools of the Oldowan industry do not represent accidental by-products of other activities that were identified as fitting for a certain task and then used in a new situation. A comparison between splintered stone fragments that gathered over time at a preferred nut-cracking site beneath a *Panda oleosa* tree in Taï National park with very simple Oldowan inventories from Omo123, Omo FtJj1 and Koobi Fora FxJj1 showed that both complexes included a large variation of fragment sizes and morphological similarities. However, they significantly vary in the selection of the raw materials. While local granites and laterites were used as hammer stones for cracking nuts, the material from the Oldowan find sites was selected for the improved control of its breaking characteristics. Local raw material was selected at the different find sites in Gona, up to 2.6 million years old (Stout et al. 2005); in the over 2.15 million year old find site Kanjera South, Kenya (Plummer et al. 1999), suitable raw materials were transported into the site. A raw material selection for hammer stones was demonstrated for the 1.8 to 1.5 million year old find sites from Bed I and II of the Olduvai Gorge (Tanzania), eponymous site for the Oldowan industry (Mora & de la Torre 2005).

In addition, other stone tool inventories, which Mercader et al. (2002) did not include in the comparison, also show characteristics that suggest that they were manufactured intentionally. Besides large quantities of artifacts in Kada Gona EG-10 and EG-12 (Semaw et al. 1997) and the high density of artifact in Ounda Gona OGS-7 (Semaw et al. 2003), it is the reduction techniques, reconstructed based on knapping marks and refits between fragments, that distinguish early stone tools from accidental fragmentation. In Lokalalei 2C, a 2.24 to 2.34 million year old find site, it was possible to refit 60 artifact sets, each composed of up to 51 flakes from one core (Fig. 56). The reduction sequences followed both uni- and multidirectional reduction from one flaking surface; both natural and prepared striking platforms were used (Roche et al. 1999). The production process in Lokalalei 2C concentrated on the reduction of flakes, not the production and forming of core tools: By adhering to certain technical rules, it was possible to achieve a high frequency of flakes per core. The impact scars on the cores and hammer stones give evidence for a very controlled striking technique (Delagnes & Roche 2005). Retouched flakes, flakes that were worked into stone tools, already show up in the early phases between 2.5 and 2 million years ago (Semaw et al. 2003; Roche et al. 1999; Delagnes & Roche 2005).

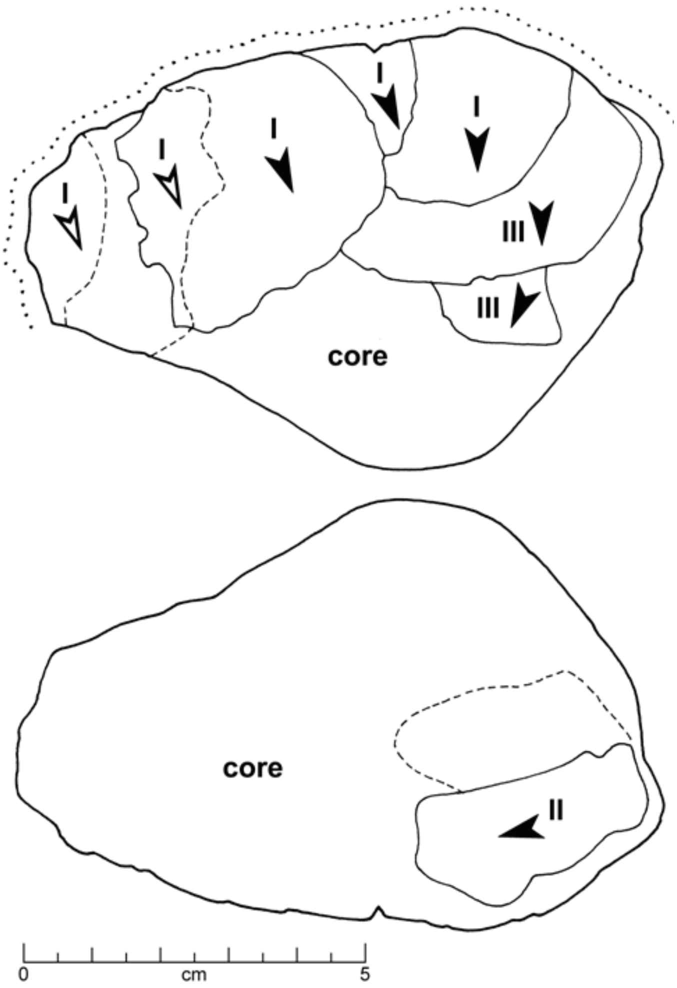


Fig. 56 Recombination of a core from Lokalalei 2C, Kenya (drawing by Achim Frey).

The preparation of the core prior to the reduction itself and the retouch of a flake after its separation both represent an expansion of the thought and action chain through additional phases, each with individual results (Fig. 57). They differ from the modifications in simple production sequences such as the preparation of a hooked probe by New Caledonian crows (*Corvus moneduloides*) (comp. Chapter 18) in their variety – it is not necessary to prepare a striking platform or retouch a flake to produce a sharp edge - and in the different phase goals. The focus shifts to the use of the tool, and thereby to the object, in the last phases of production. In the phases leading up to this point, the focus lies on facilitating and improving the tool production. Phases that do not lead to the fastest solution of the problem but that improve the effectiveness of the tool and its production are included.

Production / use of a flake tool

0. Perception basic need
0a. Perception subproblem 1
0b. Perception subproblem 2
0c. Perception subproblem 3

PHASE I: Gathering of raw material tool 1
1. Search for raw material / gathering

PHASE II: Transport of raw material tool 1
2. If necessary transport to atelier

PHASE III: Search for tool 2
3. Search for hammer

PHASE IV: Transport of tool 2
4. Transport to atelier

PHASE V: Use of tool 2 / Production of tool 1 A
5. Positioning of individual
6. Positioning raw material and hammer
7. Knapping (core preparation)

PHASE VI: Use of tool 2 / Production of tool 1 B
8. Turning core
9. Knapping (flake)

PHASE VII: Use of tool 2 / Production of tool 1 C
10. Selection of a flake
11. Knapping (retouch)

PHASE VIII: Use of tool 1
12. Use of flake

PHASE IX: Satisfaction of need
13. Direct consumption

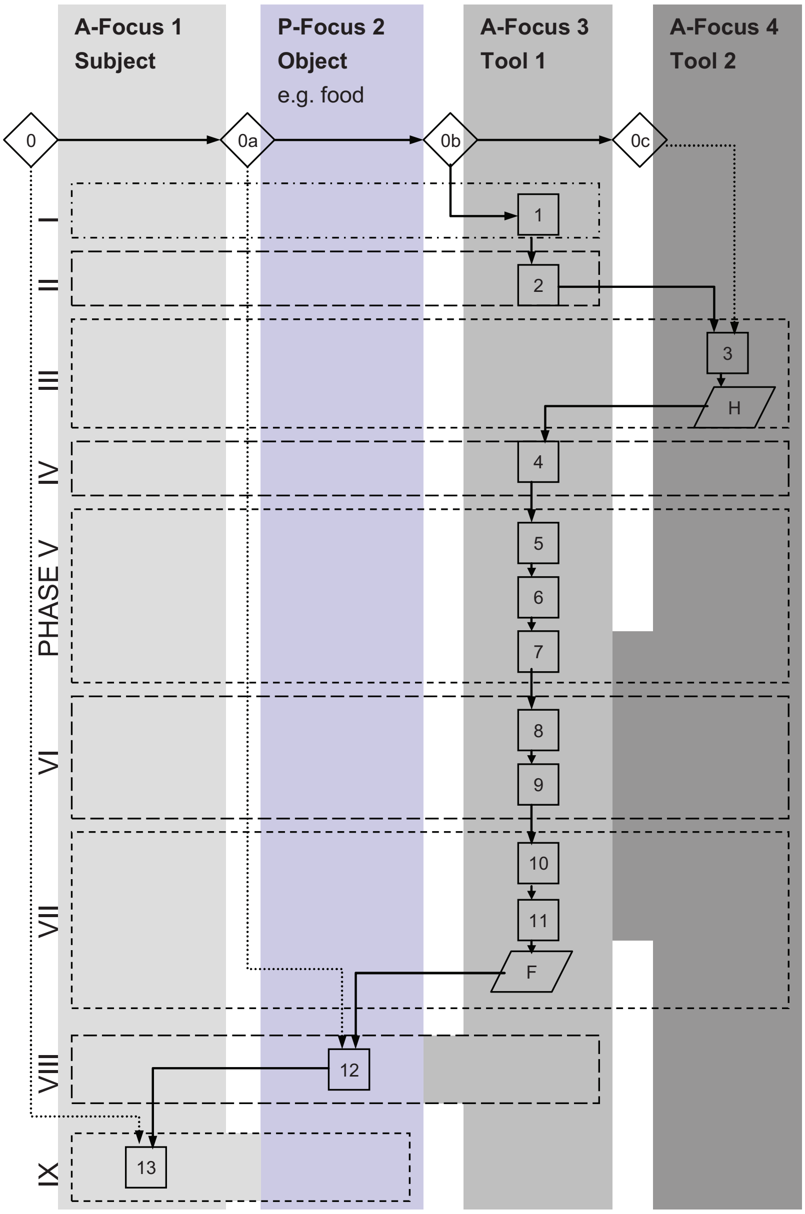


Fig. 57 Cognigram of the production and use of a flake tool. Phase V (Core preparation) and Phase VII (Retouch) are optional. If these steps are not carried out, Steps 5 and 6 in Phase V and Step 10 in Phase VIII take place.

Secondary Tools: Exclusively Human?

The production of tools using tools is generally accepted as a typically human characteristic; however, there are a few cases of animal tool behavior that could limit this exclusiveness. Write (1972) used the production of stone tools, a behavioral pattern not common to non-human primates in their natural environment, in his experiments on the ability of non-human primates to learn from humans, from another species. In various phases of training, he first showed the young orangutan Abang how to use stone tools to cut open a tied-up box containing a reward. Then Wright trained the animal to produce its own cutting tools by removing a flake from a fixed core. Abang showed that he was able to reproduce what he had learned and formed a tool with the help of another tool. The controlled handling of two movable objects did not occur because the manual abilities of the orangutan suggested that this could be too difficult for him.

In similar experiments involving freely manageable cores, Kathy Schick and Nicholas Toth (Toth et al. 1993; Schick et al. 1999) documented the developments of a bonobo's (*Pan paniscus*) manual and conceptional abilities while knapping stones, over a period of years. Kanzi learned, by observing human examples, to produce flakes from a core held in its hands using a hammer stone and then use them as cutting tools. The animal preferred a technique that he developed himself - throwing a pebble onto a hard surface or another stone - that required a great deal of strength to separate a flake from the core.

The products of the Kanzi experiments primarily differ from the Oldowan industries in the different production techniques. The striking platforms were not used consequently, leading to an obvious accumulation of some and a lack of other flake categories. The large variation of the striking angle between 50 and 125° is also a result of a lack of planning and control of the throwing technique: The average angle 89.7°, which Kanzi produced, is significantly higher than the average angle of 80° produced by direct hard-hammer percussion (Schick et al. 1999). The bonobo is principally able to produce a tool using another tool and can also control the core and hammer tool at the same time, however, when possible he prefers a simpler throwing technique where he does not need a tool to produce the cutting edge. The experiments with Kanzi confirm that the production of the early Oldowan industries was created by means of controlled and planned processes.

Although the production of stone tools has only been observed among animals in experimental situation, other tools have been described as the products of secondary tool use among wild primates as well. Yukimaru Sugyiama (1985) documented so-called brush sticks among chimpanzees (*Pan troglodytes*) in the Campo Animal Reserve, Cameroon. He interpreted the stick as having a double function as a digging stick on the blunt end and an effective termite fishing rod on the brush end. For a long time, it was not possible to observe either the production or the use of these tools. Experimental attempts by the researcher to chew on a fresh stick and form a bushy end failed; therefore, the theory that the brush end was fashioned using a stone to beat the stick and form the fibrous end was adopted. Meanwhile, Sanz et al. (2004) where able to observe that the brushed end on a termite fishing rod was produced using teeth among the Moto group in the Congo Republic. The brushed end on digging sticks or perforators were created when branches of a certain type of wood were broken off (Takemoto et al. 2005); in this case, the fibers are the result of raw material selection.

Another prominent form of object behavior, described among wild chimpanzees as "*meta-tool*" use (Matsuzawa 1996, 201), is the use of a stone wedge to stabilize and straighten an anvil used for cracking nuts (Fig. 58). Matsuzawa (1996, 203-204) analyzed the use of a wedge in tree diagrams (Fig. 59) in which he linked the freely movable objects within an action in hierarchical steps. He concludes that the use of the wedge is not directly related to the nut and that it represents a superior tool that makes the actual tool, the anvil, more serviceable.

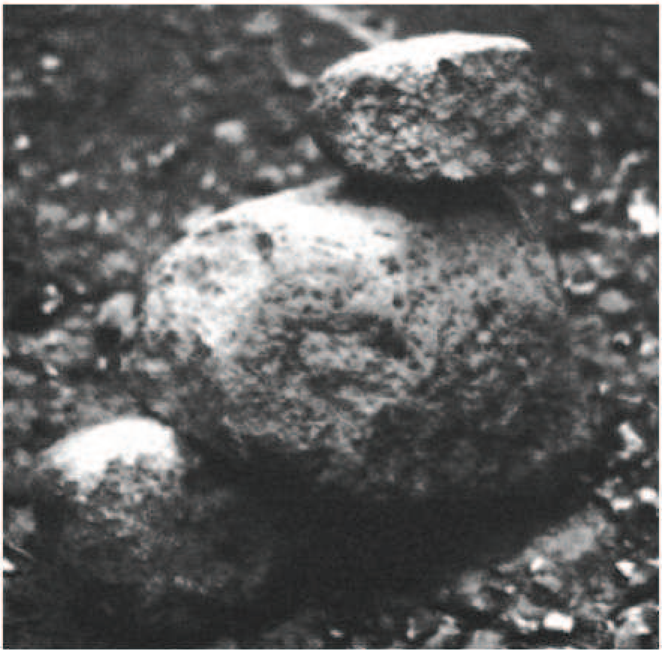


Fig. 58 Wedge, anvil and hammer: A set of three objects from the nut cracking behavior of the Bossou group, Guinea (from Matsuzawa 1996, Fig. 15.4).

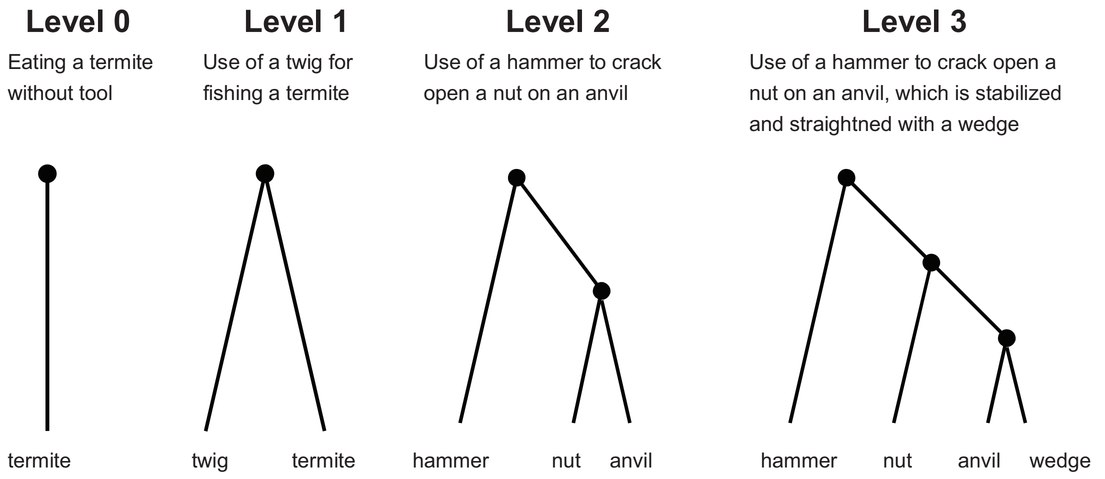


Fig. 59. Tree diagram of different tool uses among chimpanzees according to Matsuzawa (1996, Fig. 15.6).

Matsuzawa does not differentiate between passive and active action elements; hammer, anvil and wedge are all interpreted as equal tools. However, in the example of the "Drosselschmiede" (comp. Chapter 18, Fig. 29) we already established that an anvil does not represent an actively controlled tool such as a hammer does. Even if the anvil is freely movable, it remains a passive proto-tool since it is not handled when cracking open nuts (Fig. 60).

Fig. 60 Hammer, anvil and wedge used in opening nuts: Only the hammer is handled and controlled (from Matsuzawa 1996, Fig. 15.5).

The wedge does represent an element that is controlled and used to create an even anvil surface. This behavior more closely represents the stacking of boxes to form a ladder (s.a.): The wedge is not an independent tool but an element of an anvil made up of multiple pieces. The use of two stones as proto-tool anvil is therefore an example of a simple additive production format; it is the label of the stabilizing stone as "wedge" that makes one think of an independent tool.

The same can be summed up for the experiments by Santos et al. (2005) with cottontop tamarins (*Saguinus oedipus*). In an experiment to understand the *means-means-end* connections in tool use - the need for a device to get a device with which you reach the goal - the animals were offered two test scenarios. A reward was placed onto or into one object that could be retrieved using an existing connection with the help of a second object. The alternative arrangement of elements did not allow for the object with the reward to be pulled in. This experiment is meant to prove tool-oriented tool behavior as a secondary goal on the way to the problem solution, that goes beyond the simple stringing together of independent but goal oriented action phases as is the case in the termite and honey extraction sets of chimpanzees and orangutans. The test arrangement does not test tool behavior - none of the elements can be controlled to manipulate another independent object or to create a new connection - it only tests whether existing object connections are recognized and acted upon. The animals were presented with the choice between a functioning set that works as a unit and a non-functional arrangement. They were successful after some training. It is not possible to draw conclusions about secondary tool use, the use of a *meta-tool* or a *means-means-end-tool* from the experiments with the tamarin monkeys.

Among the spontaneously occurring behavioral forms involving tools in animals, the use of a wet sponge to clean a younger animal, observed by Fontaine et al. (1995) comes closest to resembling secondary tool use. A female western lowland gorilla modified the dry coconut fibers, which she had gathered, to clean her child by wetting them with water (Fig. 61). Whether the animal intended to wet the fibers with water in order to improve the cleaning abilities remains unclear, just like the question whether the animal may have observed and copied similar behavior from the animal keepers.

Sponge for cleaning a young by *Gorilla gorilla*
(after Fontaine et al. 1995)

0. Perception basic need: satisfying the basic need of the young (?)
0a. Perception subproblem 1: basic need young → cleanliness (?)
0b. Perception subproblem 2: tool necessary

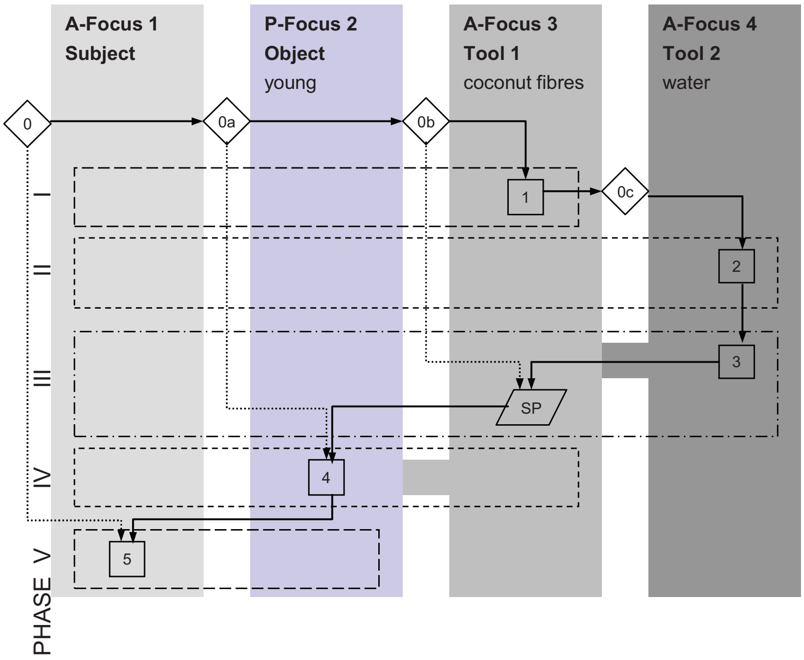
PHASE I: Search for tool
1. Collecting coconut fibres

0c. Perception subproblem 3: water necessary for production of tool 1

PHASE II: Search for water
2. Search for water

PHASE III: Modification of tool with water
3. Dipping the fibres into water

PHASE IV: Cleaning of the young
Wiping the back and bottom of the young



PHASE V: Satisfaction of need
5. Young is clean

Fig. 61 Cognigram of the production and use of a wet sponge made out of coconut fibers used to clean a younger animal by a female western lowland gorilla in captivity.

In conclusion, we must answer the question whether the use of secondary tools is a uniquely human behavior form with *yes*, insofar as researchers have not yet observed secondary tool use in wild animals. Although especially non-human primates are able to use multiple tools consecutively in different phases and can combine multiple elements into one tool that is used in one phase, the production of a tool with the help of another tool seems to be restricted entirely to humans. The earliest examples of this behavior - up to 2.6 million year old flakes used as cutting tools – are also the earliest examples for tool production, although this may be entirely due to preservation. Due to the lack of parallels in tool use among today's animals, these tools can be attributed to hominids.

However, it remains unclear whether the genus *Homo* is the exclusive producer of these stone tools. The oldest *Homo sp.* fossil KNM-BC-1, a fragment of an Os temporale from the Chemeron formation in Kenya, can be dated to a maximum age of 2.4 million years (Hill et al. 1992). It is also possible that late gracile australopithecines such as *Australopithecus garhi*, living in the region at the same period in time, could be responsible for cut marks on bones and/or stone tools (comp. Appendix II) from Ethiopian find sites (comp. Semaw et al. 2003). Analyses of the wrist bones of robust australopithecines show that they would have been anatomically capable of controlling and powerfully handling cores and hammer stones in order to produce flakes (Susman 1991, 1994, 1998). Finally, a parallel development of stone tool production cannot be ruled out, especially if we consider the performance and potential of today's non-human primates. Therefore, the question whether the use of secondary tools is an exclusively human behavioral form must be answered with *maybe*, depending on how we define humans.

Not Just Stone Tools: e.g. Digging Sticks for Termite Hills

Even though stone artifacts dominate the spectrum of archaeological finds due to their improved preservation, they are not the only evidence for early tool use. Bob Brain and Pat Shipman (1993) identified bone tools in the inventory of the South African find site Swartkrans as digging tools, based on use wear patterns and experimental comparisons (Fig. 62).

Fig. 62 A selection of bone tools from Swartkrans with significantly altered ends, traces of tool use (from Backwell and d'Errico 2001, supplemental data).

Use of bone tools from Swartkrans

0. Perception basic need: food
0a. Perception subproblem 1: open nest / extract termites
0b. Perception subproblem 2: tool for opening necessary
0c. Perception subproblem 3: tool for probing necessary

PHASE I: Search for raw material for probe
1. Search for adequate branch

PHASE II: Production of probe
2. Breaking off branch
3. Shortening / defoliation / fraying out brush end

PHASE III: Transport of probe / search for chisel
4. Transport of probe / search for bone splinter
5. Selection of a bone splinter as chisel

PHASE IV: Transport of probe and chisel
6. Transport of probe / chisel to termite nest

PHASE V: Opening of termite nest
7. Digging with chisel
8. Inspection of chisel

PHASE VI: Termite fishing
9. Extraction with probe

PHASE VII: Satisfaction of need
10. Consumption

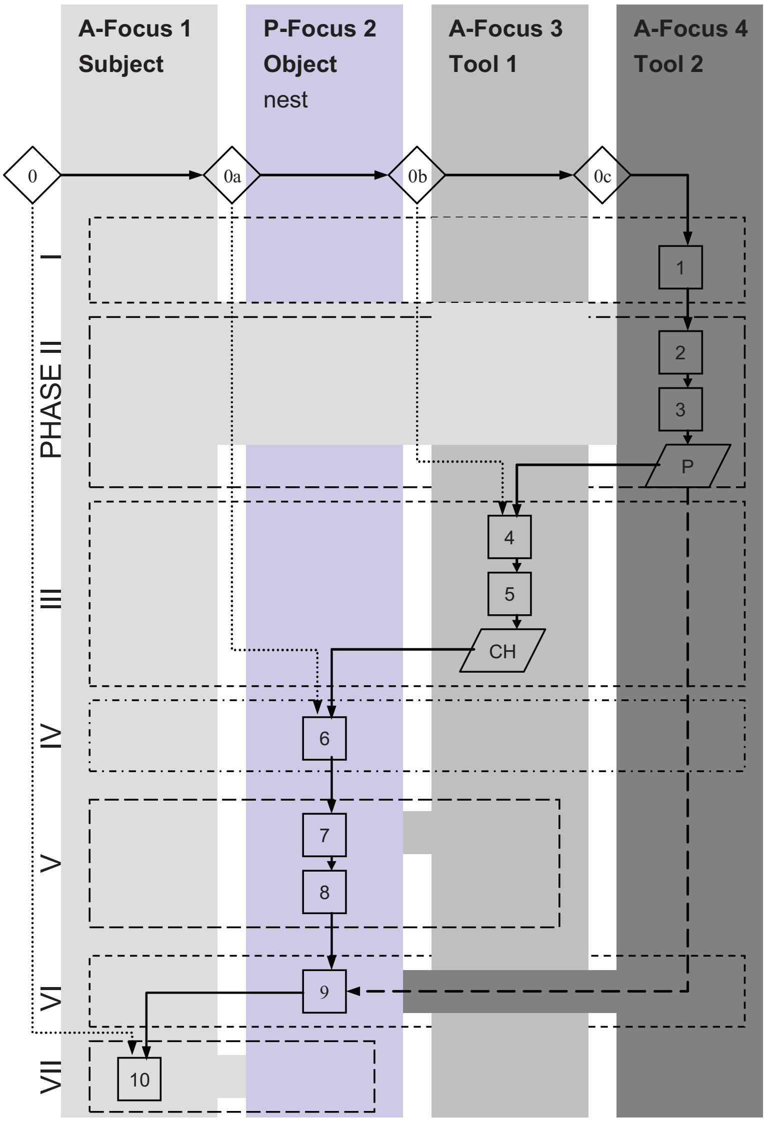
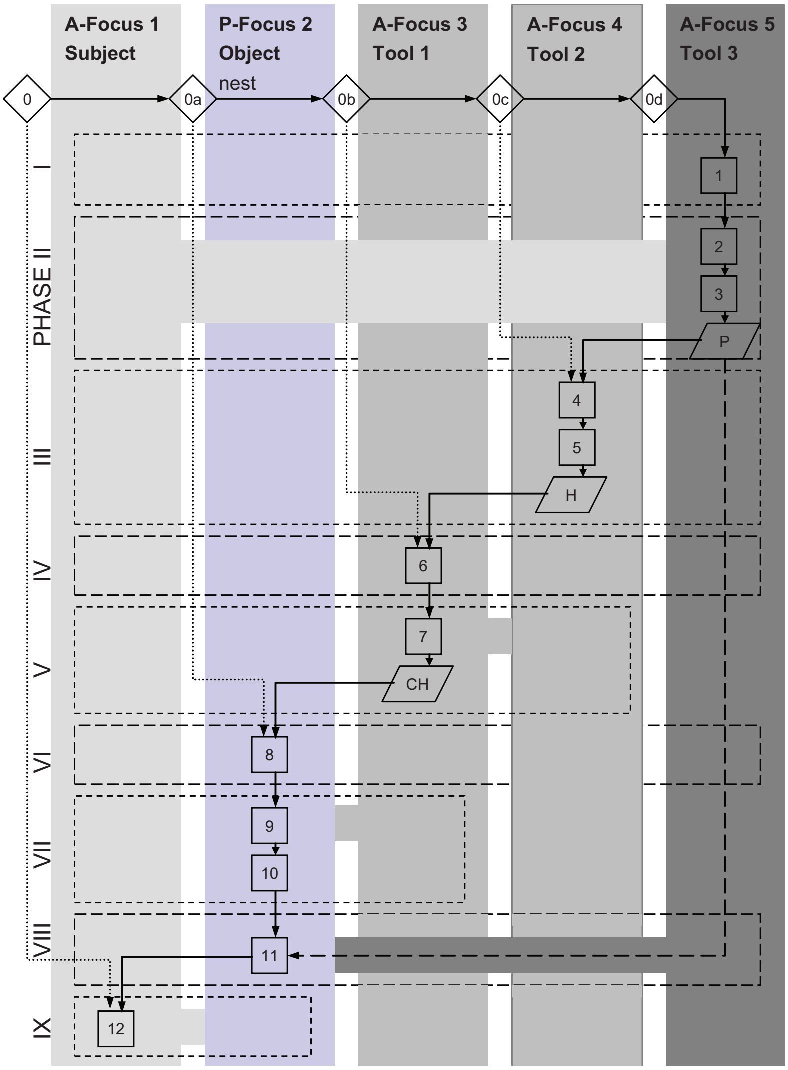


Fig. 63 Cognigram of the use of the bone tools from Swartkrans. Among the 23,000 bone fragments found in the layers Member 1-3, dated to 1.8 to 1.0 million years ago, a total of 85 artifacts with traces of use-wear were found (Backwell & D'Errico 2001, 1358). While Brain and Shipman (1993) believed that the tools were used to dig up tubers and roots, Backwell and d'Errico (2001) were able to prove through experimentation that they were used as chisels to open termite hills.

Production and use of the bone tools from Swartkrans



0. Perception basic need: hunger
0a. Perception subproblem 1: open nest / extract termites
0b. Perception subproblem 2: tool for opening necessary
0c. Perception subproblem 3: tool for production of chisel necessary
0d. Perception subproblem 4: probe necessary

PHASE I: Search for raw material for probe
1. Search for adequate branch

PHASE II: Production of probe
2. Breaking off branch
3. Shortening / defoliation / fraying out brush end

PHASE III: Transport of probe / search for hammer
4. Transport of probe / search for hammer stone
5. Selection of hammer stone

PHASE IV: Transport of probe/hammer, search for raw material chisel
6. Transport probe / hammer and search for adequate long bone

PHASE V: Production of chisel
7. Breaking up long bone / Selection fragment

PHASE VI: Transport of probe and chisel
8. Transport of probe / chisel to termite nest

PHASE VII: Opening of termite nest
9. Digging with chisel
10. Inspection of chisel

PHASE VIII: Termite fishing
11. Extraction with probe

PHASE IX: Satisfaction of need
12. Consumption

Fig. 64 Cognigram of the production and use of the bone tools from Swartkrans.

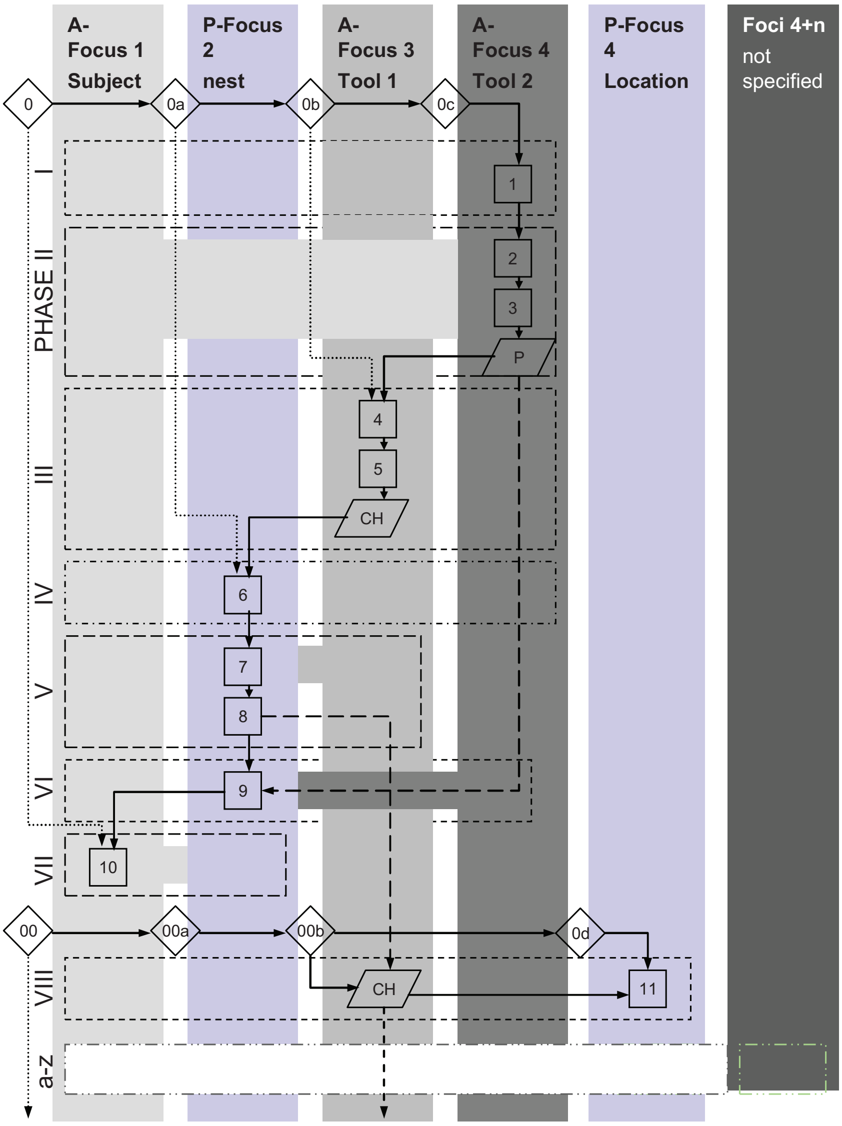
Yet if we assume that the bone was broken with the intent to fashion a digging stick from it, then a hammer stone, and with it an additional active focus of attention and an additional phase for the procurement of the hammer stone and the production of the long bone fragment, must be added to the cognigram as well as (Fig. 64). In this case, the bone artifacts would be products of secondary tool production that are then combined with a probe to form a set.

It is clear that the bone fragments were used in an activity similar to the one described by Sanz et al. (2004), where wooden perforators were used by chimpanzees as part of a termite extraction set. With this information, it is possible to develop a cognigram (Fig. 64) for the bone tools from Swartkrans that greatly resembles the diagram of the Moto group's tool set (Fig. 51). For Figure 64, we assume that the bone fragments are by-products of subsistence strategies that are used at a later point in time and independently of the consumption of bone marrow.

Once the tool has been employed and the need, which it served to satisfy, is satisfied the tool in animal tool behavior is generally left behind at or near the location where it was last employed. Tools rarely get lost between two locations and are then replaced by new ones. At the very least, chimpanzees have a memory of the location of individual hammer stones used to crack open nuts that were left behind in a certain area and that are available for re-use at that location (Boesch & Boesch 1984b). The re-use of tools is not limited to hammer stones but has also been observed for perforators, thick, robust branches, that were left behind after the entrance to the termite nests were opened (Sanz et al. 2004). The repeated use of the bone tools from Swartkrans is also probable because bone fragments in experiments only began to show use-wear patterns similar to those on archaeological finds after 15 to 30 minutes of use. Blackwell and d'Errico (2001, 1359) specify that this corresponds to the amount of time it takes to dig up a medium sized termite hill. The average time it takes to achieve a systematic perforation of a termite nest through chimpanzees was not mentioned by Sanz et al. (2004), however, the description leaves the impression that it is a significantly shorter period of time, so that it would take multiple uses to develop corresponding use-wear patterns.

The bone tools from Swartkrans were recovered together with a few stone tools and faunal remains that suggest hominid and predatory activities. Whether the entire cave or only the area near the cave entrance was used by hominids is not clear (Brain 1993c, 259), it also remains unclear whether the tools were used on site. If termite nests or hills had existed in the immediate vicinity of the entrance to the cave, then the accumulation of tools toward the inside and back of the cave could be interpreted as relocation of tools from the place where they had been left behind. If there are no termite hills in the immediate vicinity of the cave entrance, then the bone tools must have at least been brought to the entrance area of the cave (Fig. 65). Such an additional transport only makes sense if the user expects to reuse the tool at a later point in time.

Use of the bone tools from Swartkrans



0. Perception basic need: food
0a. Perception subproblem 1: open nest / extract termites
0b. Perception subproblem 2: chisel necessary
0c. Perception subproblem 3: probe necessary

PHASE I: Search for raw material of probe
1. Search for adequate branch

PHASE II: Production of probe
2. Breaking off branch
3. Shortening / defoliation / fraying out brush end

PHASE III: Transport of probe / search for chisel
4. Transport probe / search for bone splinter
5. Selection of bone splinter as chisel

PHASE IV: Transport of probe and chisel
6. Transport of probe / chisel to termite nest

PHASE V: Opening of termite nest
7. Digging with chisel
8. Inspection of chisel

PHASE VI: Termite fishing
9. Extraction with probe

PHASE VII: Satisfaction of need
10. Consumption

00. Perception basic need (semi-acute)
00a. Perception subproblem 1: need of termites
00b. Perception subproblem 2: digging tool necessary
0d. Perception subproblem 3: deposit tool at secure place

PHASE VIII: Securing of tool
11. Transport in cave

PHASE a-z: Various other activities (not specified)

Fig. 65 Cognigram of the use of the bone tools from Swartkrans with their subsequent deposition for future use.

The anticipation of a similar need in the future and subsequent actions in preparation to satisfy that future need have not been observed in the tool behavior of animals. This would require semi-acute problem awareness (Fig. 65, problem awareness 00-00b) above and beyond current needs that require an immediate solution. The preparatory action is followed by an interruption of the action chain until the special need arises again, the subject continues with activities that are independent of the first action and follow different foci of attention (Fig. 65, phase a-z). Only when the original specific need is recognized anew does the subject remember its previous action and continue with the prepared tool to the solution.

The example of the early South African bone tools is speculative. It only suggests the possibility of prognostic performance in the Oldowan, it does not prove it. This proof, however, can be found in the transport of raw materials for the production of stone tools and in the stone tools themselves.

Interruption of a Chain of Action: e.g. Transport of Raw Materials

Transport of tools also occurs in animal behavior, however, rarely across larger distances. Generally, tools and their raw materials are obtained in the immediate vicinity of the problem and within sight of the object to be worked with. Egyptian vultures (*Neophron percnopterus*), for example, use stones, which they find within 50m but also up to 4km away from the ostrich eggs they want to break open (van Lawick-Goodall & van Lawick-Goodall 1966; Becker 1993, 42). In some cases, tools are reused for multiple identical actions in different locations if the basic need has not been satisfied. Sea otters (*Enhydra lutris*) retrieve their stone anvils, which they use to open shells, from the bottom of the sea and continue to use them throughout multiple dives (Hall & Schaller 1964; Beck 1980, 42; Becker 1993). New Caledonian crows (*Corvus moneduloides*) also carry their probes from tree to tree during their search for food (Hunt 1996).

The longest well-documented transport distance of mammalian tools was identified among chimpanzees in the Taï National Park in the Ivory Coast. The chimpanzees searched for hammer stones made out of granite or laterite to open different types of nuts. The stones were primarily retrieved from within 20m of the nuts; transports of up to 200m are also frequent. They also dragged stones weighing over 9 kg over long distances. Individual hammer stones were shifted more than 500m (Boesch & Boesch 1984b). It is not clear whether this distance was bridged at once or if it represents a cumulative distance that accumulated during an action sequence with interruptions and implementation of the tool in different trees to satisfy the subject’s basic need, similar to the implementation of probes among New Caledonian crows. Numerous direct transports to targets outside the direct line of sight have been documented. Boesch and Boesch (ibid.) also recognize that hammers are selected in relation to the previously selected nut trees and according to the criteria distance and weight. The animals have a tactic and use a mental map of the area in which they memorize the location of hammers and trees in correlation to each other and compare the different distances.

The transport of raw materials and tools can be identified in archaeological materials in different ways. In large and systematically excavated inventories, the frequency of specific artifact categories, which are compared to values that were calculated using characteristics from other artifacts, can provide clues whether the element was brought into or removed from the find site. Potts (1991) and Kimura (1999; 2002), for example, were able to reconstruct that cores and flakes were removed from different Oldowan find sites based on the lack of cores of certain raw materials whose corresponding flakes were present at the site as well as the relationship of flake negatives to cores. Braun et al. (2005) see problems in this method and limit the value of such reconstructions. A survey and map of the closest raw material deposits of a find site allow an estimate of the transport distances. It remains unclear whether these distances represent direct transports or cumulative distances of multiple years and multiple individuals. Even with these uncertainties, it is possible to assume a significantly larger amount of material that is transported over greater distances for the early hominids.

Information about the frequency of raw materials at a site and the distance to raw material sources varies depending on the excavator and the quality of the area survey (comp. Appendix II). Only vague information is available about the primarily local raw material from the inventories of the early Ethiopian find sites Kada Gona EG-10 and EG-12 (Semaw et al. 1997). Howell et al. (1987) postulate a partial raw material transport of up to 20km for the find sites Omo 123 and FtJj2 of the Shungura Formation. However, the artifacts may have been displaced; therefore their age of 2.3 to 2.4 million years is not certain. In the material of Excavation 1 from Kanjera South in Kenya, dated to over 2.15 million years, 15% of the identified raw material did not come from local sources (Plummer et al. 1999). The Olduvai Gorge West Trench 57, dated from 1.78 to 1.84 million years, contained 92% quartzite, a local raw material. Three pieces of lava, whose origin is assumed to have been located 15 to 20km away were also recovered (Blumenshine et al. 2003). Raw materials from 10 to 15km away, were probably also brought into the Koobi Fora find sites KBS, HAS and NMS, all dating to 1.8 million years or older. Plummer (2004), despite individual clues to greater distances, believes that the stone raw materials in the Oldowan generally came from sources within 2 to 3km of the sites.

In the following example, I will assume a transport distance of multiple kilometers for raw materials and tools. It begins with the recognition of a need and ends with the satisfaction of the need. In this case, the distance is not cumulative. It is not a combination of multiple use episodes where the same tool is applied to multiple situations nor connected to the satisfaction of multiple needs as in the later example of the handaxe. However, we cannot assume that the entire distance was completed at once.

If we do not assume a cumulative distance where the specified object was used at each interruption, then it is very likely that the trigger for these actions was not the individual's acute basic need that had to be satisfied quickly. The future basic need is recognized and its satisfaction can be delayed for a limited amount of time. At the same time, it seems logical that a long transport can be interrupted by external influences that require the subject's attention and distract it from the objective of its actions, even if the individual attempts to continuously concentrate on the fulfillment of its goal. These reflections result in an interrupted cognigram such as the one in Figure 66.

In this diagram, the interruption occurs after the transport, similar to the securing of the tool in the Swartkrans example (Fig. 65). The search for the raw material and the transport are not triggered by the satisfaction of a need and the foresight that the same tool may be required for a similar need. Rather, a basic need in the near future and the corresponding sub-problems are recognized and trigger the actions "search for raw material" and "transport" although they are not yet acute or necessary. The actual production and use of the tool only occurs once an acute basic need arises. If possible interruptions and resumptions of thought and action chains are possible for the satisfaction of semi-acute needs, then such interruptions can also occur at different points in time: During a search for raw materials that may take longer than expected or during transport and after the acute perception of the need. It is possible that the acute problem cannot be solved as a result of such a late interruption. The ability to think with interruptions, to follow an action sequence and resume a prior string makes it possible to consciously pick up where the interruption occurred when the basic need arises again at a later point in time.

Recognizing that a tool has a continued use, as may be the case in the securing of bone tools from Swartkrans, is the basis of *curation*. This term was coined through the work of Louis Binford (e.g. 1979; 1989) and can be approximately translated with anticipatory, careful and long lasting behavior, it can be applied to raw materials, tools as well as tool sets. *Curation* expands the service life and efficiency of tools; it is the opposite of *ad hoc* use of tools where the search for the raw material only begins after the acute basic need is identified. It is usually searched for in the immediate vicinity and the tool is left behind after the need is satisfied. Bamforth (1986, cited in Odell 1996, 54) subdivides the anticipatory and long lasting behavior into five different aspects: Preparation of tools in advance, design of tools for multiple uses, transport of tools from place to place, care for existing tools and recycling. *Curation* in all of its variation has "*the net effect of prolonging the amount of time an implement remains operable within a cultural system*" (Odell 1996, 53).

Production and use of an Oldowan tool with extended raw material acquisition

00. Perception basic need (semi-acute)
00a. Perception subproblem 1
00b. Perception subproblem 2

PHASE I: Search for raw material tool 1
1. Search for raw material

PHASE II: Transport of raw material tool 1
2. Transport to atelier / raw material store

PHASE a-z: various other activities (not specified)

0. Perception basic need (acute)
0a-c. Perception subproblems 1-3 (acute)

PHASE III: Search for tool 2
3. Search for hammer

PHASE IV: Transport of tool 2
4. Transport to atelier

PHASE V: Use of tool 2 / Production of tool 1 A
5. Positioning of subject
6. Positioning of raw material and hammer
7. Knapping (core preparation)

PHASE VI: Use of tool 2 / Production of tool 1 B
8. Turning of core
9. Knapping (flake)

PHASE VII: Use of tool 2 / Production of tool 1 C
10. Selection of a flake
11. Knapping (retouch)

PHASE VIII: Use of tool 1
12. Use of flake

PHASE IX: Satisfaction of need
13. Direct consumption

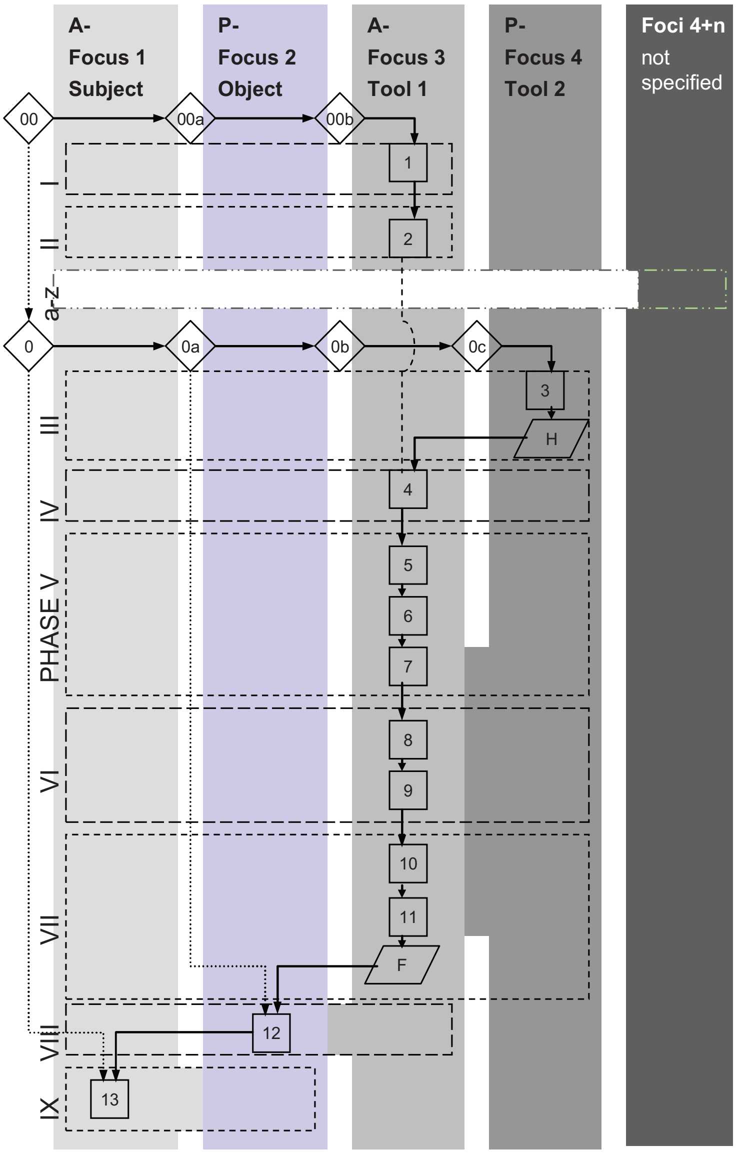


Fig. 66 Cognigram of the production and use of an Oldowan tool with an interruption of this thought and action chain through phases a-z.

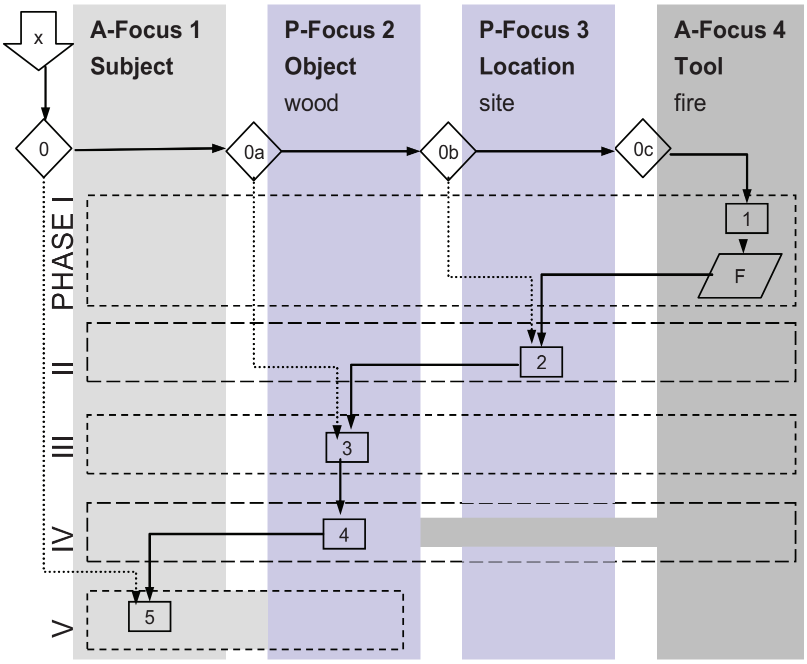
Although the anticipation of an action chain and the – minor – anticipatory production of the necessary tools has been documented for the extraction sets of chimpanzees of the Moto group (Sanz et al. 2004), the trigger for the action in animals remains the acute perception of a basic need. The possible securing of the bone tools from Swartkrans may represent an early variation of care and maintenance of existing tools: A similar need as the one that was just satisfied is recognized for the near future and the tool is deposited for safe-keeping, to be used again when the need arises. A third aspect of *curation,* the transport of raw materials and tools, can be proven for the beginnings of human tool production and also for semi-acute needs in the near future.

Thinking and acting with tools already becomes independent of the perception of an immediate necessity in the Oldowan. The time frame is thereby significantly increased into the near future. Simple planning and organization of actions can be carried out above and beyond the necessary immediate steps. Archaeological remains cannot encompass the entire spectrum of this advanced thinking-around-the-corner. Yet individual clues shed light on the possibilities that arise.

About the Maintenance of Tools: e.g. Use of Fire

One of the earliest traces for the controlled use of fire are the burned bone fragments from layer Member 3 in the South African find site Swartkrans (Brain 1993b), dated to 1.5 to 1 million years before present based on fauna and cultural material remains. The preceding layers Member 1 and 2 as well as Member 1 *hanging remnant* contained almost no burned bones, the 270 pieces identified in Member 3 were spread over numerous square meters and throughout the entire layer. Bob Brain (1993b, c) concludes that these findings are the result of the controlled use of fire in the area near the cave entrance. Individual burned bones could be the result of an accidental bush fire that also burned wood near the entrance of the cave; however, the large quantity and regular distribution of the burned pieces in Member 3 provide evidence for the recurring presence of fire. The Swartkrans excavator does not believe that the fire was started on site, but that grass fires, similar to today's fires, were used, which are the result of lightning bolt strikes during thunderstorms at the start of the summer rainy period in October and November (Brain 1993c, 262).

Maintenance of a fire as a source of warmth



Perception stimulus fire →

0. Perception basic need: warmth
0a. Perception subproblem 1: need of burning wood at the site
0b. Perception subproblem 2: staying at the site
0b. Perception subproblem 3: need of tool for kindling

PHASE I: Search for tool
1. Search for / selection of a smouldering branch of the fire

PHASE II: Transport of tool
2. Transport to site

PHASE III: Gathering of wood / object which is acted upon
3. Gathering of firewood / fuel

PHASE IV: Use of tool
4. Kindling fuel

PHASE V: Satisfaction of need
5. Consumption of warmth

Fig. 67 Cognigram of the maintenance of a fire as a source of warmth and/or protection.

The cognigram for the controlled use of fire in the entrance of Swartkrans is relatively simple (Fig. 67). Besides the subject focus “warmth” and “protection”, an additional attention focus, a burning branch as carrier of the fire, is opened and impacts another piece of wood, the object. The location also represents an additional passive focus since it is selected, not determined through one of the other foci. The need can be satisfied with very few action steps in five phases. If it is necessary to first produce a tool, to light a branch using an existing fire, then another phase of production is added. At first glance, the cognigram of the use of fire at Swartkrans resembles the use of fire to drive prey out of hiding (Fig. 68) by an Australian bird of prey, probably the black kite (*Milvus migrans*) (Lockwood in Boswall 1977 in Beck 1980, 25; Becker 1993, 62). It is said that the animals grasp glimmering branches from areas where the bush fires have already burned down and drop them over unburned areas in order to catch small animals fleeing from the newly kindled fire.

Use of fire to drive prey out of hiding by *Milvus migrans*
(after Beck 1980; Becker 1993)

0. Perception basic need: food
0a. Perception subproblem 1: attaining hidden prey
0b. Perception subproblem 2: bushfire drives prey out of hiding
0c. Perception subproblem 3: tool necessary

PHASE I: Search for tool
1. Search for glimmering branch

PHASE II: Transport of tool
2. Transport to unburned area

PHASE III: Use of tool
3. Dropping the glimmering branch over an unburned area
4. Newly kindled bushfire / prey fleeing from the fire

PHASE IV: Catching of the prey
5. Catching of the prey

PHASE V: Satisfaction of need
6. Direct consumption

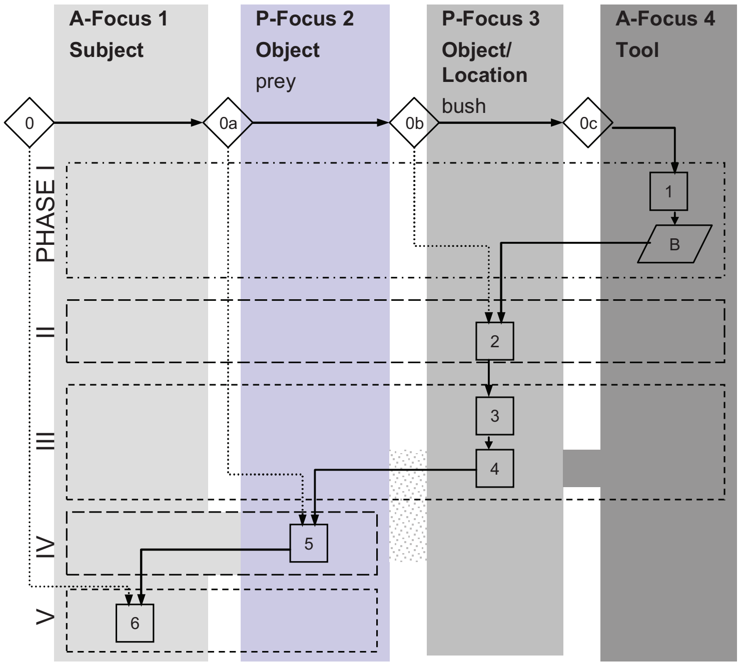
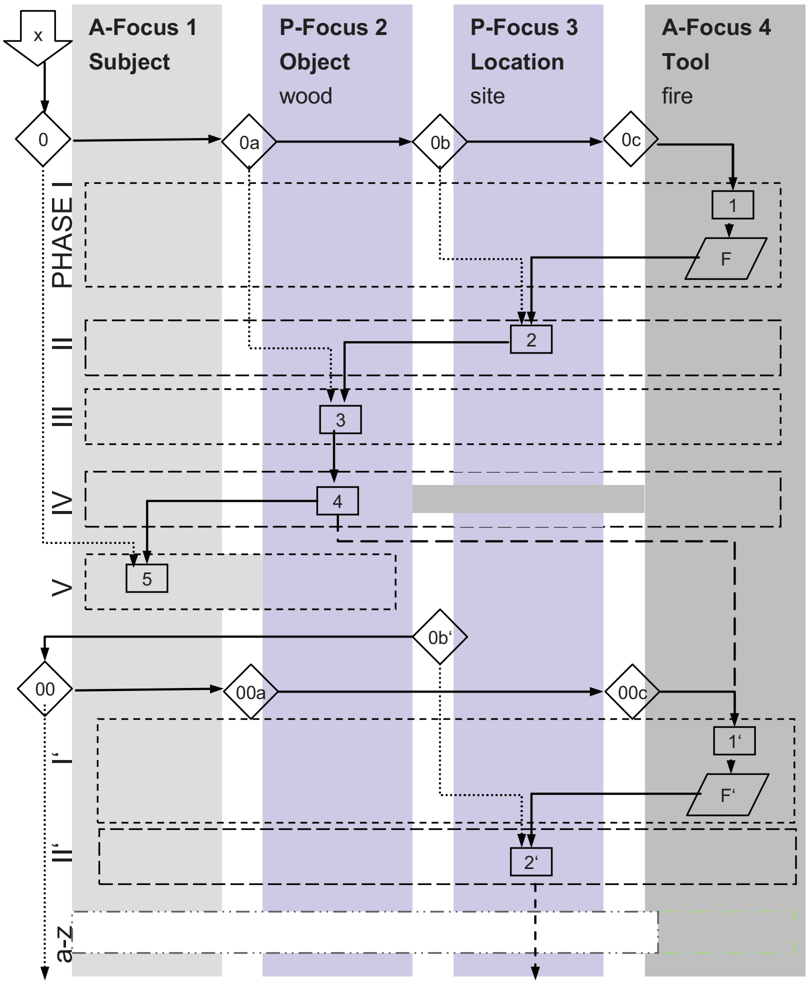


Fig. 68 Cognigram of the use of fire through Australian birds of prey (black kite?).

However, the use of glimmering branches by black kites does not represent tool use because the branch is not handled actively or focused on the target object. It more closely resembles the use of bait (such as insects, feathers and bread) by different species of heron (comp. Chapter 18). In contrast, the probable use of fire through hominids does represent tool use since the glimmering branch is not simply used to start an unspecific conflagration, but to light up and monitor a small scale, limited amount of material. In the South African find site Swartkrans the possible fire users are the robust australopithecines, whose presence at the site is verified through fossil bones in the same layer, as well as *Homo ergaster*, who lived in the same region at the same time. Similar evidence for the controlled use of fire is known from the almost 790,000 year old Israeli site of Gesher Benot Ya'aqov in the form of burned flint flakes and pieces of wood (Goren-Inbar et al. 2004). The tool users in this case belong to the group of middle Pleistocene *Homo*, although the species cannot be clearly identified. Burned fragments of bone were also found in the oldest, ca. 500,000-year-old layer Level 10 from the Chinese *Homo erectus* cave Zhoukoudian. Due to the lack of ash and charcoal remains, Weiner et al. (1998) question the presence of the postulated fire pit and do not see direct evidence for the maintenance of an *in situ* fire.

Relocating a fire as source of warmth (direct)



Perception stimulus fire →

0. Perception basic need: warmth
0a. Perception subproblem 1: need of burning wood at the site
0b. Perception subproblem 2: being at the site
0b. Perception subproblem 3: need of tool for kindling the fire

PHASE I: Search for tool
1. Search and selection of a smouldering branch of the fire

PHASE II: Transport of tool
2. Transport to site

PHASE III: Gathering of wood / object which is acted upon
3. Gathering of firewood / fuel

PHASE IV: Use of tool
4. Kindling fuel

PHASE V: Satisfaction of need
5. Consumption of warmth

0b‘. Perception subproblem 2‘: change of site
00. Perception basic need: warmth (semi-acute)
00a. Perception subproblem 1: need of burning wood
00c. Perception subproblem 3: need of tool for kindling fire

PHASE I‘: Search for tool
1‘. Search and Selection of a smouldering branch of the fire

PHASE II‘: Transport of tool
2‘. Transport while search of new site

🟩 **PHASE a-z**: various other activities (not specified)

Fig. 69 Cognigram of the relocation of a fire, the source of warmth, when moving to a new campsite.

The problem-solution distance shows that the short-termed controlled use of fire is not an exceptional form of tool use. However, the evidence for the use of this, from a modern point of view, very useful tool is rare and begins late in human evolution. This is only in part due to poor preservation and the difficulty to differentiate between traces of natural fire and fire controlled by humans. Aside from the elements required to make use of a fire, these elements had not been part of the typical activity spectrum, - a glimmering branch as tool, production and use of tool through lighting objects that are not yet burning - it is the continuous occupation with the fire to keep it alight and alive, that hindered its regular use. The required anticipatory perception of semi-acute basic needs and the pursuit of a thought and action chain with interruptions through other problems and solutions have been observed in other forms of tool use. The maintenance and relocation of a fire to another campsite may simply have taken place in the manner illustrated in Figure 69.

In contrast to the previously described thought and action chains with interruption in which the tools were either put down at a specific location and not considered until they were required again (Fig. 65) or where the tool was carried but did not require further maintenance (Fig. 66), a glimmering branch requires continuous care and attention or *curation*. It cannot be carried all day and put down someplace on the way without further attention and then picked up again in the evening to light the next fire. To keep the glimmering branch intact as a tool, the active subject could light small fires throughout the day without a specific acute basic need to produce a follow-up tool. Actions without acute or semi acute basic needs are always in competition with other actions for which an immediate need is felt. A high degree of abstract thinking and strong self-discipline is necessary to weigh the competing problem solutions and keep the individual from giving in the acute need. Another possibility is the use of a transport container in which the glimmering branch can be carried and remains functional until it is needed again. The advantage is that the tool can be carried along without having to pay further attention to it. However this solution requires a significant expansion of the problem-solution distance (Fig. 70).

Aside from the active focus of attention of the function (A-Focus 4), an additional sub-focus of continuous functionality must be activated for the tool (A-Focus 4'), which was not necessary for the simple use of fire. This action must take the changing nature of the tool and the time factor of the action into consideration. It is not just necessary to anticipate the basic need and pieces of the thought and action chain, but also to anticipate the problems involving the characteristics of the tool that can occur over a longer period time and develop solutions for them. Even more, the effect of the tool container does not show an immediate or directly observable result so that finding a suitable solution turns into a very complex undertaking.

Relocating a fire as a source of warmth (with help of a container as transport tool)

0b. Perception subproblem 2: change of site
00. Perception basic need: warmth (semi-acute)
00a. Perception subproblem 1: need of burning wood
00c. Perception subproblem 3: tool 1 for kindling necessary
00c'. Perception subproblem 3': maintenance of tool 1 during duration of transport necessary
0d. Perception subproblem 4: tool for transport necessary

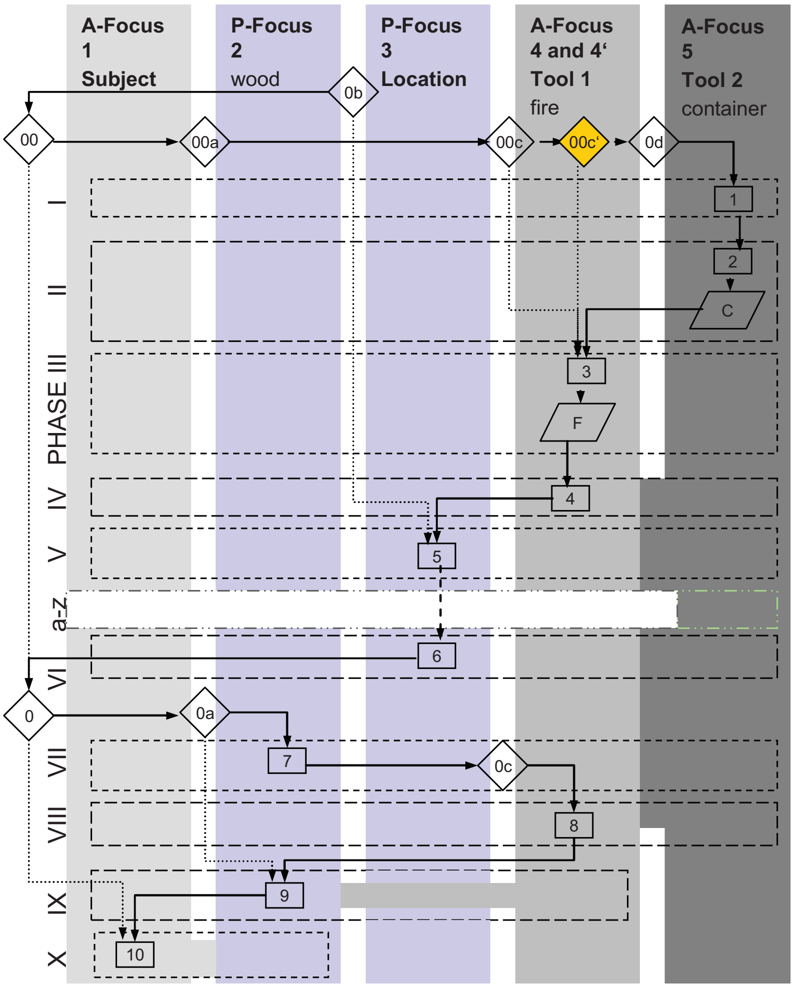
PHASE I: Gathering of raw material for tool 2
1. Gathering raw material (e.g. leaves)

PHASE II: Production of tool 2
2. Production of tool 2

PHASE III: Search of tool 1
3. Search / Selection of a smouldering branch

PHASE IV: Storage of tool 1
4. Placement of smouldering branch in container

PHASE V: Search for new site
5. Transport of tool 1 in tool 2



PHASE a-z: various other activities (not specified)

PHASE VI: Selection of new site
6. Establishment of new site

0. Perception basic need: warmth (acute)
0a. Perception subproblem 1: need of burning wood

PHASE VII: Gathering of firewood
7. Gathering of firewood

0c. Perception subproblem 3: tool for kindling

PHASE VIII: Removal of tool 1
8. Taking smouldering branch out of the container

PHASE IX: Use of tool 1
9. Kindling of fuel

PHASE X: Satisfaction of need
10. Consumption of warmth

Fig. 70 Cognigram of the transport and use of a fire as a source of warmth taking continuous maintenance, e.g. through a container as transport tool, into consideration.

If we look at the use of fire as a tool together with the follow-up problems, it becomes clear why fire did not belong to the regular tool set for a long time: Even after the discovery of the use of a glimmering branch lit from a natural fire, the use of fire probably remained infrequent. Depending on the regional frequency, glimmering branches could be retrieved from natural fires, started by e.g. strikes of lightning, volcanic activities or pyrophoric peat. They were useful and burned for as long as the basic need was active. When the basic need was satisfied, the fire had little chance of surviving as long as the subject was not capable of larger abstract thought (s.a.). Evidence for the controlled use of fire is not an indicator for making fire as Goren-Inbar et al. (2004) postulated for Gesher Bent Ya'aqov. The problem-solution distance for making fire is even greater than the long-term care for an existing fire.

The use of a container to maintain the characteristics of the tool "glimmering branch" has not been proven archaeologically. Due to the complexity of the thought and action chain and the large problem-solution distance, the use of such a container probably only occurred hundreds of thousand years after the simple use of fire was documented for Swartkrans, at a point in time when different tools with similar complex cognigrams arise.

Feedback in the Thought and Action Chain: e.g. the Handaxe

Beside the use of fire, handaxes are the subject of the heaviest debates concerning tool use in the early Paleolithic. Handaxes are oval to almond, heart, drop or lance-shaped tools, whose lengths range between 10 to 25cm - rarely larger or smaller -, whose front and back are worked bifacially. They usually have a thickened, blunt heavy end and robust cutting edges on the side that run out into a thinner prepared point. Large flakes, pebbles or cores of different lithic raw materials were used as the raw form for these bifacial tools; large bones were also used (e.g. Tromnau 1983, Villa 1991). Classic handaxes (fig. 71) can be surprisingly symmetrical both along the long axis and in the cross-section. This symmetry triggered the debate about the intentionality of the form and possible intended symbolism for this artifact type (Holloway 1969; Wynn 1985; Graves-Brown 1995; Kohn & Mithen 1999; Porr 2000).

Proto-handaxes have been documented for the developed Oldowan, they are very similar to the first rough handaxe forms from the slightly younger Acheulian. Chronologically, handaxes have been documented from 1.6 million years ago, e.g. in Konso-Gardula, Ethiopia (Asfaw et al. 1992), to the end of the middle Paleolithic circa 40,000 years before present. Their geographic distribution ranges from Africa, Central and Western Europe as well as Western and Southern Asia. It was believed until recently that the distribution of handaxes was limited to this region south of the so-called Movius-line (Movius 1949), however, circa 800,000 year old finds from the Bose basin in southern China (Hou et al. 2000) and an undated find from the Philippine island Luzon (Pawley 2002a; 2002b) prove that there were at least individual occurrences of the artifact type beyond this line.

Fig. 71 Carefully shaped bifacial classic handaxe (Find site St. Même, France. Collection of the Institute for Pre and Protohistory and Medieval Archaeology, Department for Early Prehistory and Quaternary Ecology, Eberhard Karls Universität Tübingen. Photo: Hilde Jensen)

Handaxes are frequently considered to represent a type fossil for the middle and younger early Paleolithic, however, their form and degree of preparation varies greatly depending on the raw form and degree of reduction (Ashton & McNabb 1994; McPherron 2000). In early Acheulien find sites, roughly formed pieces with very little edge and cross-sectional symmetry predominate. In the middle Pleistocene, the frequency of finely crafted and significantly more symmetrical handaxe forms increases. A comparison of find sites from the same time period shows a great variation in the frequency of this classical handaxe form. Early handaxe-carrying Acheulian inventories were contrasted with non-handaxe techno-complexes, such as the Clactonian in England and other contemporary pebble industries in Europe and Africa. Current more detailed analyses suggest that the shift from one type of industry to another shows a flowing transition rather than, as has been previously postulated, clear technological divisions (White 2000).

In their discussion of the function of handaxes, Davidson and Noble (1993, 365) point out the *finished artefact fallacy*: Since the reduction process is made up of different stages and some form details have technological advantages, we should not assume that the classic handaxes we find were intentionally fashioned as such. The authors go even further and postulate that handaxes are the by-product of bifacial blade reduction and should be interpreted primarily as cores, not as intentionally produced tools. However, the different reduction phases do not necessarily prove that flakes were the final product. The production of a carefully worked handaxe includes different stages: Roughing out, thinning and finishing. Different fully functional flakes are created at each stage of the production process. It does not make sense to interpret the finishing as preparation of a core, since this frequently occurs directly prior to the rejection of the core.

The core hypothesis and other extreme interpretations for the function of handaxes – projectiles for hunting (Jeffreys 1965; O'Brien 1981; 1985; Calvin 1993) or fixed horizontally in the ground to scrape hides (Kleindienst & Keller 1976) – are brought into perspective through trace-wear analyses of the tools (e.g. Keeley 1980; Albrecht et al. 1984; Veil et al. 1988; Binnemann & Beaumont 1992; Sala 1996). Specific edge-wear patterns and polishes show that handaxes were probably used as tools to work with meat, hides and bones, less frequently with wood and other plant materials. Experiments have shown that the handaxes are very good butchering knives, primarily for cutting open and skinning medium to large mammals (Jones 1980). Ashton and McNabb (1994) focused on the variability of the tool and the robusticity of its edges, easy transportation and the possibility for long use of the tool through sharpening of the edges. These characteristics make handaxes the ideal tools for unforeseeable butchering tasks.

Whether the carefully worked, classic handaxes also had symbolic value, remains a matter of speculation. Porr (2000) believes that handaxes also incorporate social information, allowing them to function as tools for integrating their owner into social systems. Kohn and Mithen (1999) interpret the symbolism of especially well-formed, even and symmetric handaxes as a product of sexual selection, similar to a peacock's tail feathers, where those males are selected as sexual partners, whose excellent subsistence strategies allowed them sufficient time and leisure to produce the finest and most complex handaxes to be presented as dowry.

In order to find an interpretation for the function of handaxes and to produce a Cognigram, it is important to come to terms with the temporal dimensions of the production, use and possible reworking of the tool. Hallos (2005) offers an enlightening summary. A short story of handaxes that do not show significant interruption of the action chains from the first stages of production from the local raw material to use and discard can be observed in the British find sites

Caddington and Boxgrove. Beside the butchered horse from the so-called horse butchery site of Boxgrove (Quarry 2 GTP 17), it was possible to reassemble numerous cores of local flint. All reduction stages from roughing out, thinning out with a soft blow and the finishing stage as well as the handaxes themselves were found, thereby illustrating the thought and action chain from the first acute recognition of the basic need, uninterrupted, to its final satisfaction.

Beside these snapshots, other find sites encompass even longer handaxe life cycles. Indicators for these cycles are the evidence for the transport of raw materials and tools into or away from the find site such as in Kilombe, Kenya (Gowlett 1991; 1993), Olorgesailie / Kenya (Issac 1977; Potts et al. 1999) and Elandsfontein, South Africa (Klein 1978; Avery 1988). Multiple phases of rework and sharpening of the tools, such as those identified by McPherron (2003) at the Israeli find site Tabun are also evidence for these cycles. Hallos (2005) used recombination to investigate the material from four middle Pleistocene find sites in north-western Europe, Cagny l'Epinette Level H, Ferme de l'Epinette Level MS, Elveden Area III, Beeches Pit Area AH, all of which were located right next to raw material deposits. Evidence for the import and export of raw materials and for phases of reworking and the export of newly sharpened tools was found.

Due to the different production methods that were identified based of archaeological findings and the different lengths of time the handaxes were used, I will present three different cognigrams for this tool type:

- For the production and use of a simple handaxe that is prepared using only a simple hammer stone and has a short period of use (Fig. 72). The handaxes corresponding to this cognigram were found in early African find sites and among the less classic pieces of other regions.
- For the production of a finished handaxe that is roughened out in one or more phases, thinned out and then finished, with a short life-span and limited to a specific episode of a recognized and satisfied need (Fig. 73). The handaxes from the *horse butchery site* of Boxgrove are used as the model for this cognigram.
- For the production of a finished handaxe that is roughened out in one or more phases, thinned out and then finished, with a long life-span and used in a number of individual episodes of recognized and satisfied needs that also include an interruption of the thought and action chain, as well as phases for transport and reworking (Fig. 74). Evidence from the French find sites Cagny l'Epinette Level H und Ferme de l'Epinette Level MS (Hallos 2005) is used to illustrate this cognigram.

Production and use of a rough handaxe (with hammer stone, short life span)

0. Perception basic need: food
0a. Perception subproblem 1: dismember a carcass
0b1. Perception subproblem 2: tool necessary, which at the same time is good for cutting....
0b2. Perception subproblem 3: ...and heavy duty purposes
0c. Perception subproblem 4: second tool necessary to produce the first tool

PHASE I: Search for tool 2
1. Search for hammer stone

PHASE II: Transport of tool 2 / search for raw material for tool 1
2. Search for adequate raw material in vicinity

PHASE III: Transport of tool 1 and raw material for tool 2 to object
3. Transport

PHASE IV: Production tool 1 / use of tool 2
4. Positioning of subject
5. Positioning of raw material and of hammer stone
6. Roughing out
7. Perception subproblem 2 & 3, control of results
8. Perception subproblem 2 & 3, adaptation of actions
9. Turning of blank

PHASE V: Use of tool 1
10. Use of handaxe

PHASE VI: Satisfaction of need
11. Consumption

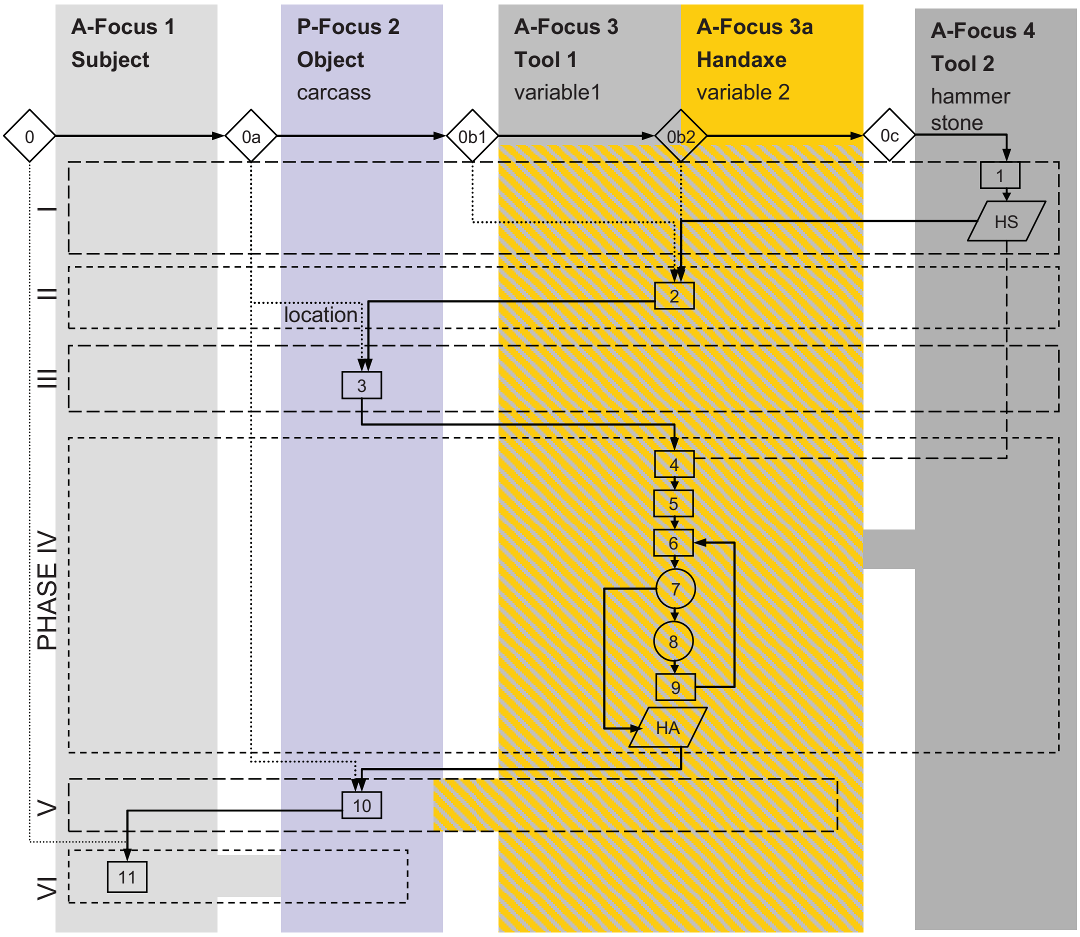


Fig. 72 Cognigram of the production and use of a rough handaxe with a short life span.

The cognigram of the rough handaxe with a short life-span (Fig. 72) varies the common production process of a tool using a second tool and additional phases such as the search for raw materials and tools, transport, production of the tool, its use and, finally, satisfaction of the need. A rough handaxe is a relatively complex tool to produce due to numerous important variables (comp. Wynn 1979), all of which are important for its function – attention foci 3 and 3a. It requires „*a mental construct, not necessarily an idealised shape, but a concept of the artefact as a functional form*" (Ashton & McNabb 1994, 190). In order to reach such a complex functional form, the producer must continue to compare the current stage of production with the mental concept of the desired object and constantly adapt and alter his method. Phase IV simplifies and summarizes the most important steps, which are repeated, as is indicated by the arrows pointing against the general process direction.

Conceptual control and adjustments (Steps 7 and 8) were not necessary in the previously described thought and action chains since simple tool forms were based on a functional form concept that could be reached through independent steps.

The problem-solution distance is significantly increased by the form concept, which requires constant control and adaptation. The individual steps are not linear but in a feedback loop.

The problem-solution distance in the cognigram of the finished handaxe with a short life-span (Fig. 73) is increased – in addition to the feedback loop between the different production phases (8 and 9, 8' and 9', 8'' and 9'') - through the use of a second, additional tool for the fine finishing of the handaxe. We previously introduced the necessity of two different tools to reach the solution of a problem in the termite extraction sets of the chimpanzees of the Moto group (Sanz et al. 2004, comp. Fig. 52). However, two different secondary tools are required for the rough and fine working of a handaxe, the tool that is needed for the solution of a basic problem. Soft-hammer percussion, using hammer stones made out of soft stones and percussors out of organic materials such as bone, antler or hardwood, were used for the thinning out and finishing phases on archaeological materials. In Figure 73, a soft hammer stone will be used for better understanding. Modern day flint knappers prefer to use organic pressure flakers (Newcomer 1971), which require additional phases and tools for their production. Such tertiary tool use will be discussed in the following chapter. Possible additional sharpening phases, which may be inserted between use phases and satisfaction of the basic need, will be discussed in the last example involving handaxes (Fig. 74).

Production and use of a finished handaxe (with hard-hammer and soft-hammer percussion, short life span)

0. Perception basic need: (acute) food
0a. Perception subproblem 1: dismember a carcass
0b1. Perception subproblem 2: tool necessary, which at the same time is good for cutting....
0b2. Perception subproblem 3: ...and heavy duty purposes
0c. Perception subproblem 4: tool 2 for roughing out of tool 1 necessary (hammer stone)
0d. Perception subproblem 5: tool 3 for finishing of tool 1 necessary (soft hammer stone)

PHASE I. Search for tool 3
1. Search for soft hammer stone

PHASE II: Transport of tool 3 / search for tool 2
2. Search for hammer stone

PHASE III: Transport of tool 2, 3 / search for raw material tool 1
3. Search for adequate raw material in the vicinity

PHASE IV: Transport of tool 2, 3 and raw material tool 1 of object
4. Transport

PHASE V: Production of tool 1 / use of tool 2 → Roughing out
5. Positioning of the subject
6. Positioning of the raw material and hammer stone
7. Roughing out
8. Perception subproblem 2 + 3, control of results
9. Perception subproblem 2 + 3, adaptation of results
10. Turning of blank

PHASE VI: Production tool 1 / use of tool 3 → Thinning
11. Positioning of the raw material and the soft hammer stone
12. Thinning
8'. Perception subproblem 2 + 3, control of results
9'. Perception subproblem 2 + 3, adaptation of results
10'. Turning of blank

PHASE VII: Production tool 1 / use of tool 3 → Finishing
13. Finishing
8". Perception subproblem 2 + 3, control of results
9". Perception subproblem 2 + 3, adaptation of actions
10". Turning of blank

PHASE VIII: Use of tool 1
14. Use of hand axe

PHASE IX: Satisfaction of need
15. Consumption

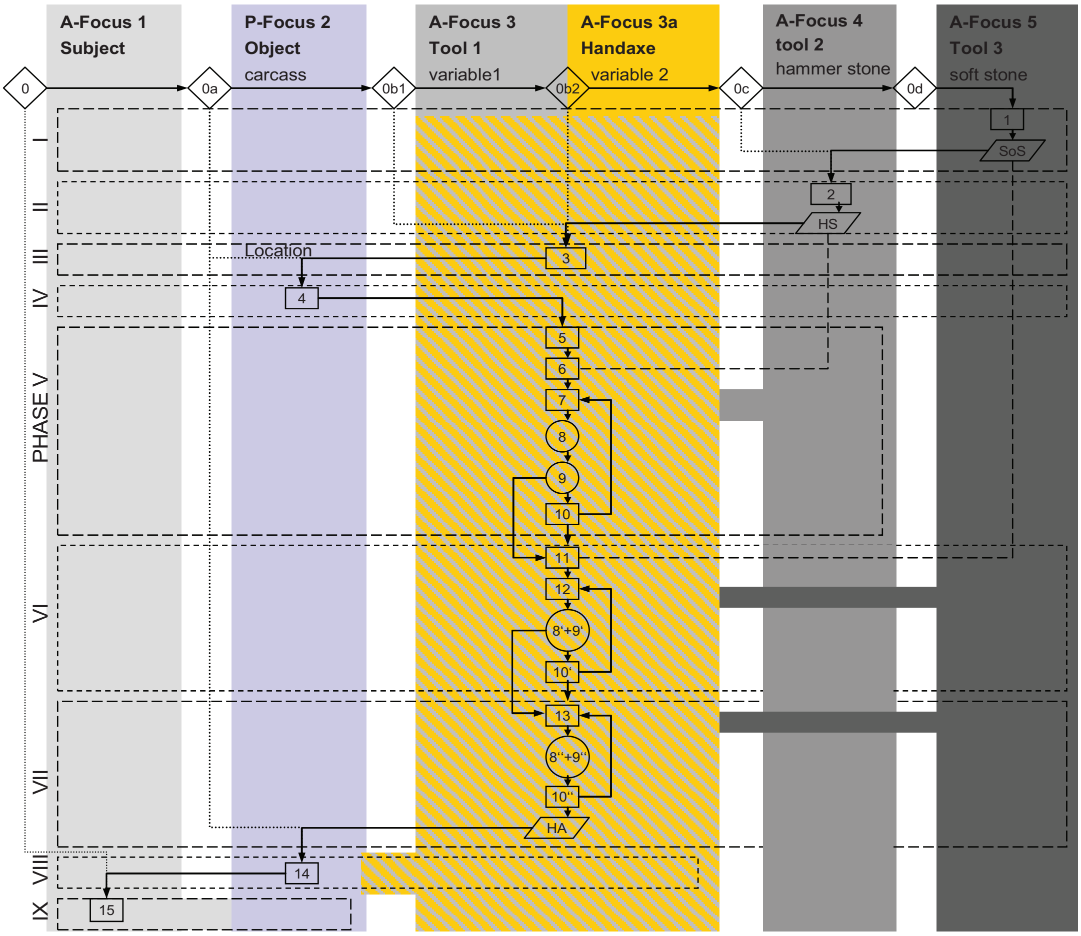


Fig. 73 Cognigram of a finished handaxe with a short life span.

The production of a fine finished handaxe with clear and symmetrical edges and profile requires a persistent focus on the production of the tool. Modern flint knappers can produce comparable tools in a maximum of 15 to 45 minutes. Modern replicas reproduce the finished handaxe. Possible additional thinning out and finishing as part of possible retouch phases cannot be completely reconstructed; therefore it is incorporated into the production phases. Following a form and function concept with constant control of the results and adaptation of the steps requires an increased detachment of the actions from the initial recognized specific need, even in 15 minute production sequences. The expenditure of different production phases with different tools improve the handaxe tool. However, this expenditure is not necessary in order to satisfy the acute need for food. The problem-solution distance increases.

When we take a look at the cognigram for the long-term use of a finely worked handaxe (Fig. 74), the diagram seems to become more and more incomprehensible and confusing, similarly to the hypothetical Cognigram for the transport and use of a fire that required continuous care and maintenance and included a container for transport (Fig. 70). The individual elements of the long thought and action chain however, are only a combination of the known phases described in the above-mentioned production processes for a carefully manufactured handaxe, an interruption by additional tasks that do not belong to the foci of attention of this chain of operation and a renewed uptake of the handaxe chain at a later point in time.

Phases X and XI, additional sharpening of the tool, were inserted into the example prior to the satisfaction of the need. This does not seem likely in cases where the basic need is food. However, if we include other basic needs such as the need for warmth / protection, therefore, the desire for the hide and fur of the animal previously hunted for food, then the inclusion of an additional tool-working phase prior to the satisfaction of the first basic need seems plausible.

The handaxes with a long life-span, e.g. Cagny l'Epinette Level H and Ferme de l'Epinette Level MS (Hallos 2005), are especially interesting because they document the first evidence of the combination of the proactive production of a tool and its tactical application for the satisfaction of more than one need. New Caledonian crows transport their probes from branch to branch (Hunt 1996) within one thought and action chain that is completed with the subject's satiation. Even the chimpanzees in the Taï National Park (Boesch & Boesch 1984b) stopped using hammers to open nuts when their hunger was satisfied. They remember where they deposited their hammer stone, but this memory only becomes relevant to the action when a new need and desire for the nuts is recognized. The bone tools from Swartkrans (Brain & Shipman 1993; Blackwell and d'Errico 2001) may represent the anticipation of the renewed use of a tool when the need arises again: The transport of raw materials and tools in the Oldowan represent an anticipation of a need, however, tool use ends with the satisfaction of the need. Individually, the proactive production of a tool and its tactical implementation in more than one thought and action chain are not unusual. In combination, they represent additional evidence for an increased abstraction of a tool from a specific need, which leads to an uncoupling of tools and specific needs.

Production and use of a finished handaxe (with hard-hammer and soft-hammer percussion, long life span)

00. Perception basic need: (semi-acute) food
00a. Perception subproblem 1: dismembering a carcass
00b1.Perception subproblem 2: tool necessary, which at the same time is good for cutting....
00b2.Perception subproblem 3: ...and heavy duty purposes
0c. Perception subproblem 4: tool 2 necessary (hammer stone)
0d. Perception subproblem 5: tool 3 necessary (soft stone)

PHASE I. Search for tool 3
1. Search for a soft hammer stone

PHASE II: Transport of tool 3 / search for tool 2
2. Search for hammer stone

PHASE III: Transport of tool 2, 3 / search for raw material of tool 1
3. Search for adequate raw material in the vicinity

PHASE IV: Production of tool 1 / use of tool 2 → Roughing out
4. Positioning of the subject
5. Positioning of the raw material and the hammer stone
6. Roughing out
7. Perception subproblem 2 + 3, control of the results
8. Perception subproblem 2 + 3, adaptation of actions
9. Turning of the blank

PHASE V: Production of tool 1 / use of tool 3 → Thinning
10. Positioning of the raw material and the soft hammer stone
11. Thinning
7‘. Perception subproblem 2 + 3, control of results
8‘. Perception subproblem 2 + 3, adaptation of actions
9‘. Turning of blank

PHASE VI: Production tool 1 / use of tool 3 → Finishing
12. Finishing
7“. Perception subproblem 2 + 3, control of results
8“. Perception subproblem 2 + 3, adaptation of actions
9“. Turning of blank

PHASE VII: Transport of tool 1, 2, 3 to object
13. Transport

PHASE a-z: various other activities (not specified)

0. Perception basic need: (acute) food
0a. Perception subproblem 1: dismember carcass
0b1. Perception subproblem 2: tool necessary, which at the same time is good for cutting…..
0b2. Perception subproblem 3: ...and heavy duty purposes

PHASE VIII: Search tool 1
14. Search of handaxe

PHASE IX: Use tool 1
15. Use handaxe
0a‘. Perception subproblem 1: dismembering a carcass
0b1‘. Perception subproblem 2: tool necessary, which at the same time is good for cutting….
0b2‘. Perception subproblem 3: ...and heavy duty purposes → sharpening!
0c‘. Perception subproblem 4: tool 3 necessary

PHASE X: Search tool 3
1‘. Search for soft hammer stone

PHASE XI: Production tool 1 / use tool 3 → reworking
12‘. Finishing
7‘“. Percepton subproblem 2 + 3, control of results
8‘“. Perception subproblem 2 + 3, adaptation of actions
9‘“. Turning of blank

PHASE XII: Use tool 1
15‘. Use handaxe

PHASE XIII: Satisfaction of need
16. Consumption

00‘. Perception basic need: (semi-acute) food
00a‘. Perception subproblem 1: dismembering a carcass
00b1‘.Perception subproblem 2: tool necessary, which at the same time is good for cutting…..
00b2‘.Perception subproblem 3: ...and heavy durty purposes
00c. Perception subproblem 4: tool 2 necessary (hammer stone)
00d. Perception subproblem 5: tool 3 necessary (soft stone)

PHASE XIV. Search for tool 3
1“. Search for soft hammer stone

PHASE XV: Transport of tool 3 / search for tool 2
2‘. Search for hammer stone

PHASE XVI: Search for tool 1
14‘. Search for handaxe

PHASE XVII: Transport of tool 1, 2, 3, search for object
13‘. Transport

PHASE a-z: various other activities (not specified)

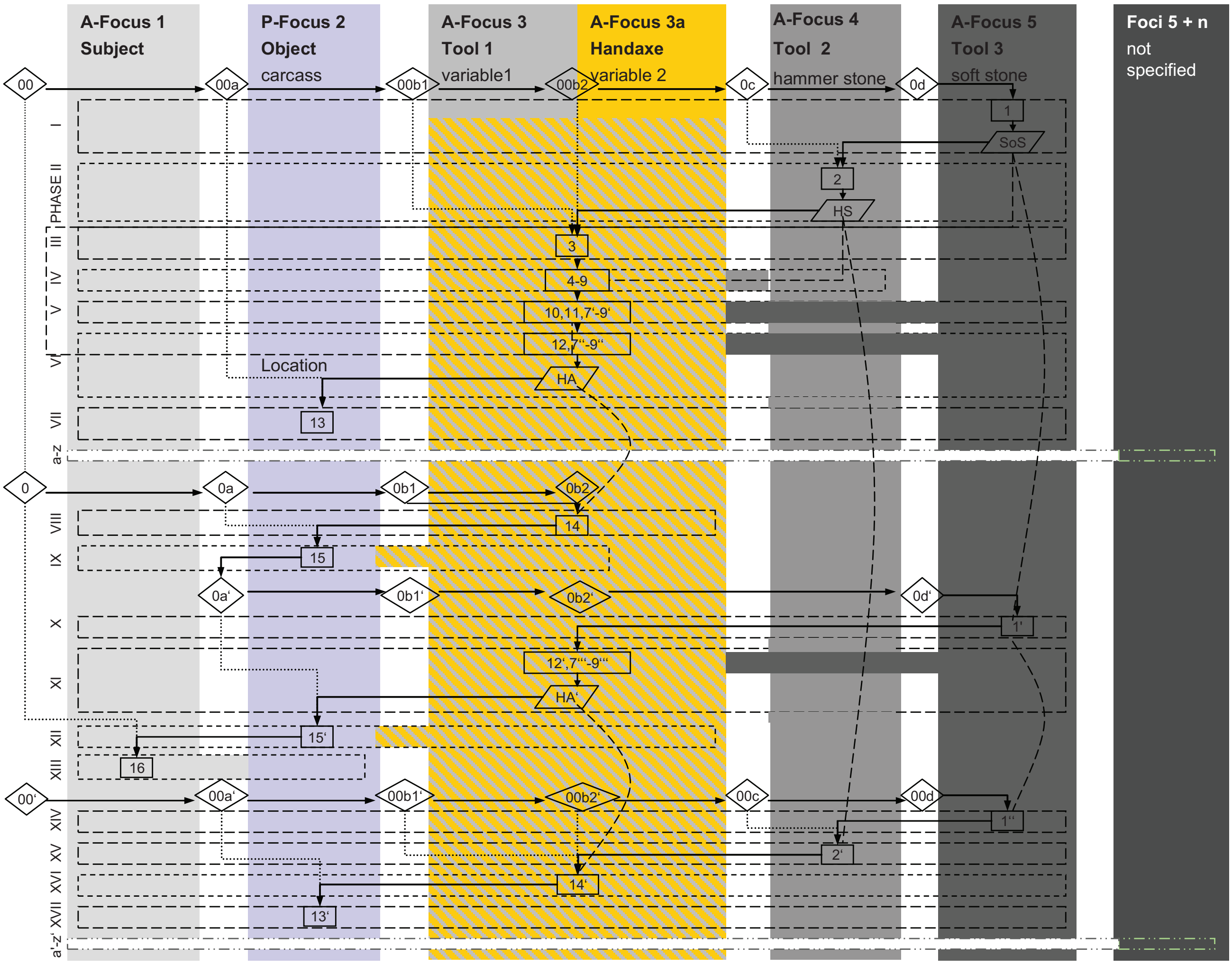


Fig. 74 Cognigram of the production and use of a rough handaxe with a long life-span.

Small Steps Away from the Acute Need: The Beginning of Human Problem-Solution Behavior

Human behavior involved in finding solutions for problems using tools shows a significant expansion of the problem-solution distance starting with the earliest evidence for stone tools. This is a case of thinking in circles: If the tools we recognize as being of human origin were no different from previously existing tools made by animals, then we would not be able to identify their hominid origins. Yet it is remarkable that tools produced by hominids are not distinguished through their choice of raw materials, tool form or use context but primarily through the extended problem-solution distance. Oldowan stone tools are made out of stone like some of the hammers chimpanzees used to open nuts. These can splinter during use and still be used in a subsistence context. The difference is the intentional splitting of stones using a second tool, a hammer stone, to create flakes with which the food can be cut or scraped. Tools are not only implemented for the direct solution to a problem. Hominids recognized the possibility to use a tool in order to produce another tool with characteristics that cannot be achieved by manipulating the raw form with hands, teeth, claws, etc. The knapper recognizes the possibility to better manipulate the target object using other tools and must also apply the same principle to the production of the tool. This requires an increased awareness of the problem: On the one hand, the necessity for different tool characteristics required to work the target object and, on the other hand, the recognition of the possibility to achieve these characteristics (cutting) using a second tool. The use of secondary tools expands the distance between the basic problem and its solution by inserting an additional active attention focus into the solution process.

The problem-solution distance in human behavior is expanded early on due to a delay in the problem's solution. Additional active foci of attention that do not directly influence the target object but the tools, which in turn influence the target object, build a multi-linked chain of influence. The basic need is not recognized as an acute need requiring an immediate satisfaction, but as semi-acute. Such a future need can be triggered through the satisfaction of a current need, during which similar problems and the renewed need for the same tool arise. From this, it is possible that the functional tool is secured for renewed use in the future, as has been discussed for the bone tools from Swartkrans. A future action is prepared; the tool is ignored throughout the following interruption of the thought and action chain until a new acute need is recognized.

The problem may also be recognized as semi-acute for the future, thereby requiring a continuous thought and action chain. During the transport of raw materials and tools over a large distance of multiple kilometers, we can assume that the distance was not covered in one session and that other problems arose and required the subject's attention on the way. This could lead to an interruption of the chain of operation that can only be taken up again after the intermediate problem or need is resolved. The semi-acute recognition of the original need is still kept active throughout the interruption, even if it is not kept in the foreground of the subject's awareness. The continuation of a chain of thought and bridging an interruption with an independent attention focus increases the effectiveness of tool behavior by allowing problem solutions with elements that cannot be found, or can only be found with great difficulties, in the immediate vicinity. It includes the possibility to encompass poor environments and the ability of the acting subject to act upon and alter its environment.

The previously discussed thought and action chains were achieved by linking independent steps to each other. The production of handaxes, however, requires feedback loops to continuously control the results and adjustments in the action sequences, when necessary, in order to realize the envisioned product. Due to the variability of forms and the degree of finishing of handaxes, we cannot assume that an underlying ideal concept for the classic symmetrical handaxe form exists for all handaxes. However, the pattern of a functional form with multiple significant variables is mirrored in all the different varieties of handaxes. And this form cannot be achieved through accidental reduction of individual flakes. It must be controlled and adjusted using a bifacial reduction technique.

Generally, at least two different secondary tools are required for the production of finely worked handaxes. The use of a handaxe to satisfy a need – together with the feedback processes – significantly increases the attention focused on the tool and its production and pushes the satisfaction of the original basic need into the background. Finally, long-term use of tools, as it occurs in the combination of proactive production and tactical reuse of handaxes in multiple episodes of the recognition and satisfaction of needs, is an additional indicator for the increasing separation of human tool behavior from semi-acute or acute and definitely from concrete problem recognition.

The term *curation* can be summed up as the recognition of continuous usefulness of a tool. The development of *curation* can be traced back to rudimentary forms throughout the Lower Paleolithic to the beginning of the Middle Pleistocene, ca. 780,000 years ago. The recognition of a problem and the interaction with elements of the chain of operation prior to an acute need is evident in the securing of tools for future use, in the proactive transport of raw materials for Oldowan tools as well as in the production and transport of handaxes. Individual tools are kept in good repair by depositing them in specific locations instead of discarding them after a need has been satisfied and, as evidenced by some handaxes, through reworking and sharpening them in order to keep them functional. Additionally, some carefully prepared handaxes seem to have been produced in order to serve multiple independent purposes.

The beginning of *curation* and the increasing separation of tool behavior from concrete needs are heralds of a revolutionary development in the problem-solution distance that did not only influence modern tool behavior but made it possible. The early signs and the influence of the separation of tool and need will be discussed in the following chapter.

20 Decoupling of Tool and Need

In animal tool behavior, thought and action chains are triggered by the perception of a basic need and end with the satisfaction of that need. Tools are produced and used in order to satisfy a specific need; after the need is satisfied, the tools are discarded. Animals rarely remember the location where they deposited their tools, such as in the case of stone hammers among chimpanzees in the Taï National Park (Boesch & Boesch 1984b) or, possibly, the robust wooden perforators used to open earthen termite nests (Sanz et al. 2004), in order to reuse them at a later point in time. Even among the most intensively studied chimpanzee groups, it has so far not been possible to observe that the chimpanzees prepared or secured tools, which they just finished using, for future use.

On the one hand, thought and action chains in human tool behavior can be activated by an acute basic need and end with the satisfaction of that need. On the other hand, semi-acute needs that are expected to arise in the near future also activate specific actions. Thirdly, modern humans can recognize needs in general: They prepare, procure, care for, repair and secure tools even without the recognition or anticipation of a specific acute or semi-acute problem. Our own economy depends upon it – as demonstrated in hardware stores, clothing stores, bookshops and our own homes etc. The consumer world of products can only be produced by people that do not only act to satisfy a specific need which they recognized for themselves or others, they recognize general problems and begin to act as a result. In the following chapter, I will discuss the decoupling process of tool and need and the resulting consequences for human tool behavior.

Living Tools: e.g. the Spear

Due to poor preservation, wooden artifacts are rare in archaeological materials: They only occur in a handful of Paleolithic sites such as in the Acheulian layers of Kalambo Falls on the border between Tanzania and Zambia (J.D. Clark 2001), Bilzingsleben in Thuringia (Mania & Mania 1998) or the Middle Paleolithic Abric Romaní in Spain (Carbonell & Castro-Curel 1992). Usually, the finds are very fragmented or heavily weathered and the form, production steps or function can no longer be identified, as in the case of an object made out of willow wood from Gesher Benot Ya'akov, Israel, which is described as board-like with polish (Belitzky et al. 1991; Goren-Inbar et al. 2002). Lucky finds, such as the point of a spear made out of yew wood (length 387mm, max circumference 36mm), found in 1911 at the English find site Clacton-on Sea (Oakley et al. 1977) and dated to the Middle Pleistocene Hoxnian-warm period, are very rare. A similar find is the “lance”, made out of yew wood, which was broken into eleven fragments by the weight of a falling forest elephant, from Lehringen in Lower Saxony, Germany. The spear is ca. 120,000 years old and has its origins in the last warm period, the Eem. It is 239cm long and ca. 31mm in diameter at its widest point near the base (Thieme &Veil 1985; Veil 1991).

The find sites in the coal-bearing region around Schöningen in Lower Saxony currently encompass the largest and best-preserved complex of wooden tools, dated 300 – 400,000 years ago. Besides Schöningen 12, dated to the Reinsdorf interglacial, probably oxygen isotope stage OIS 11, which produced four cleft hafts made out of pinewood, Schöningen 13, dated to the late Reinsdorf interglacial, offers a look at the possible frequency of wooden tools that would not be preserved under normal conditions. A tool made out of a small spruce wood stem whose side shoots and bark were removed was interpreted as a throwing stick, based on ethnographic parallels. The tool, 78cm long, a maximum diameter of 3cm and carefully worked pointed ends, was probably used to hunt birds. A 88cm long staff, previously broken, made out of spruce wood with a maximum diameter of circa 3.6cm was also decorticated and trimmed. The stumps of the side shoots are, all but one, carefully worked and smoothed out. The staff is tapered towards the ends, one end is charred. Due to the charred ends and its proximity to two fire pits, the staff is currently interpreted as a skewer or poker (Thieme 1999).

Seven spears made out of spruce wood (Fig. 75) and an additional fragment of a spear point complete the inventory of wooden tools from Schöningen 13 (Thieme 1997; 1998). All spears where decorticated and smoothed, the branch stubs where removed and the points carefully prepared. The lengths vary between 1.82 and 2.5m, the largest diameter between 29 and circa 50mm. The center of weight is located in the front third of the staff, similar to modern day tournament javelins (Thieme 1999). Throwing experiments with reconstructions of the spears from Schöningen demonstrate the good throwing characteristics for distances up to 15m (Rieder 2003).

Fig. 75 One of the seven javelins made out of spruce wood from Schöningen, Lower Saxony. (picture by Nicholas Conard)

We do not have data about the production techniques for spears from Schöningen, such as the data from experimental reconstructions gathered by McNabb (1989) for the reproduction of the Clacton spear or by Veil (1991) from the Lehringen lance. Based on three reconstruction attempts, Veil suggests a production time of 4.5 to 5.5 hours, which includes felling the tree, trimming the branches, smoothing the branch stubs, decortication, reworking the surface and whittling of the point. However, the preparation from the raw form to the finished spear only represents a fragment of the chain of operations from the production to the use of the spear. The procurement and production of the stone tools required to prepare the lance are not included.

In order to fell a small tree and prepare a spear or a similar wooden tool, it is not sufficient to use an unmodified tool. You must first make a cutting or hacking tool, usually with the help of an additional tool. In this case, tool use is not secondary – using a tool to produce a second tool – put tertiary: A tool is used to produce another tool that is needed to produce a third tool, which is required to solve the original problem. An additional active focus of attention is not simply added to the thought and action process, it is added to a chain of actions that are built up hierarchically upon each other. Tertiary tool use is already probable for the production of

Middle and Upper Pleistocene handaxes (Haidle 1999; 2000; 2004b; comp. Chapter 19). Soft-hammer percussion used for thinning out and finishing the handaxes from Boxgrove, was probably carried out using tools made out of organic materials, such as percussors made out of antlers, that – as opposed to hammer stones - need to be produced first. The stone tools brought into Schöningen 13 II-4 were also sharpened on site, probably using soft-hammer percussion. Bone retouchers that may have been used to sharpen the stone tools were found at the site.

The production of wooden spears requires the previous production of tools; experiments have shown - as in the production of carefully worked handaxes – that the use of different tools in the various phases simplifies the production process. We can assume that the need for the production and use of different tools was anticipated. The production of these tools encompasses the search for suitable raw materials, on the one hand and, on the other hand the search for or production of suitable additional tools. An example is illustrated in the following action chain (Fig. 76):

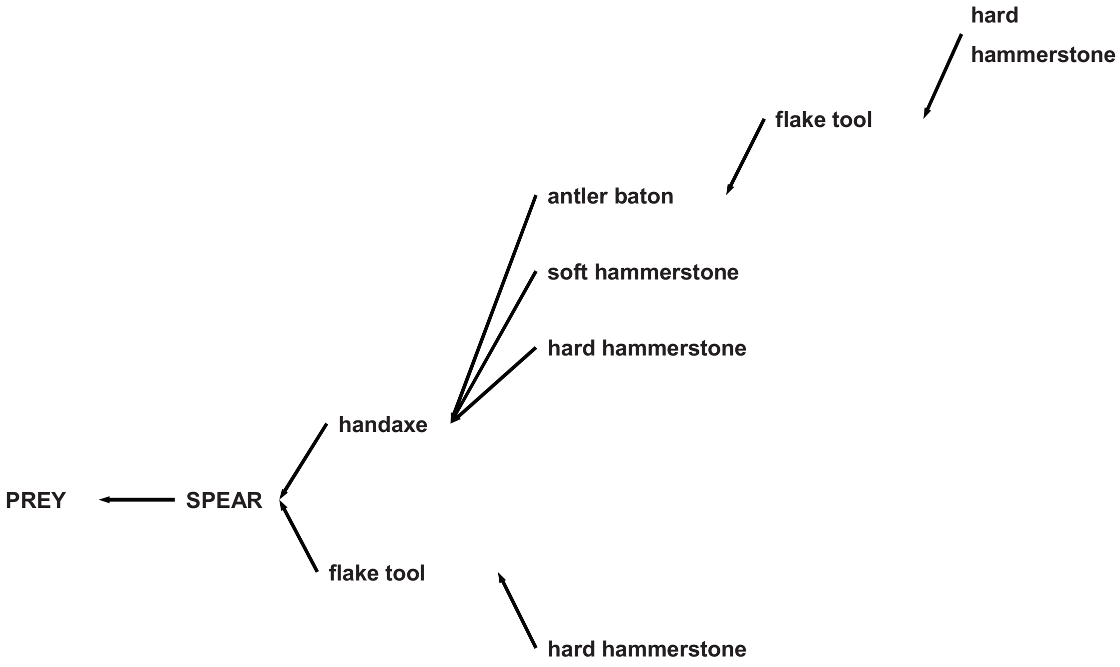


Fig. 76 Possible effective chain of the tools that are required for the production and use of a hunting spear.

The production of a spear is not limited to the production phases involving the wooden raw materials – such as in the experiment of the Lehringen lance – but also includes the search for the wooden raw materials and additional phases for the search for raw materials made out of stone and the search for or production of tools. Figure 77 shows the cognigram for the production and use of a spear. The individual phases and their succession were developed for the spears from Schöningen based on observations of Veil's (1991) experiment. The diagram represents a possible, very probable, yet not binding, scenario.

It includes the most important foci of attention and phases, yet it could be extended if, for example, we assume that an antler percussor or a bone retoucher were used instead of a soft hammer stone to finish the handaxe. In this case, we would have to include additional phases with an additional tool and an addition attention focus. For purposes of clarity, I have refrained from including descriptions and illustrations of the individual steps in each phase; what these steps look like in detail can be inferred from the previously described thought and action chains in Chapter 19. The cognigram for the use and production of a javelin in Figure 77 is significantly simplified and abstracted. However, it would be very uncomfortable to pursue such a chain of operation beginning with the recognition of the basic need, food (meat), to its satisfaction, as in the previously described examples and as it was still plausible in the case of the hand axe.

A solution was suggested in Chapter 19 – the increased separation of a tool from an acute need. Solutions can be found for a semi-acute need in the future or for additional needs other than for the acute one. A hard hammer stone is required at three possible points in the effective chain illustrated in Figure 76. It is possible that the subject used the same hammer stone three times for the production of three different tools and secures the stone so that it can be used again when a situation arises in the future. Tools are increasingly decoupled from specific problems and begin to have their own significance. The production of a tool is no longer triggered by a real basic need such as food, scratching an itch, defense or entertainment that can be satisfied through the application of the tool. The production of tools can be activated through the recognition of a principle problem whereby the satisfaction – since there is no specific need – is not achieved through the application of the tool but in the satisfaction of having principally provided a solution.

Complex thought and action chains such as the production and use of a spear are only practical when the tool and specific need are decoupled since the satisfaction of the original need (eat meat) would take a number or days. Decoupling tool and need means that the chain of operations is not a unit as illustrated in Figure 77, but a combination of different units that can be combined freely: The production of a handaxe, the preparation of a hard and soft hammer stone, the preparation of an antler percussor, the production of a flaked tool, the production of a spear. The individual production phases are supplemented by the specific or general search for raw materials. The independent units handaxe, flaked tool, percussor, hard hammer stone, soft hammer stone, spear are combined in a common thought and action chain through their application in producing another unit as well as through common phases of transport and combined use. Since these elements are not used exclusively for the satisfaction of a basic need, but as independent units that are also applied in parallel chains of operation, these thought and action chains (Figure 77) can no longer be viewed as a static unit. They are constructs that are the result of a combination of existing elements and additional elements that need to be found or produced.

Tools begin to have their own significance independently of specific basic needs. It is not clear, when this began: It was a slow process and the archaeological remains are fragmentary. The beginnings of the decoupling can be seen in the recognition of semi-acute problems as, for example, in the raw material and tool transport of the Oldowan, more than 2 million years ago. The advanced decoupling of specific problems and tools as a solution is illustrated in tertiary tool use, probably in the carefully worked handaxes, definitely in the production of wooden spears for hunting 300,000 to 400,000 years ago.

Decoupling the problem and the solution has significant consequences for both ends of the thought and action chain of tool use: First, for the circle of recognized problems and situations that can possibly be solved using tools and secondly for the volume of possible solutions. Problem recognition that is no longer limited to specific basic needs makes it possible to recognize how we can further influence and manage our surroundings. It is only possible to search for a solution to change a situation if we recognize that the situation can be manipulated with the help of tools. Dividing thought and action chains into manageable subsets makes it possible to identify new solutions and possibilities. Various elements can be combined freely because they are independent, not restricted to a specific intended use, thereby making it possible to experiment freely with objects and tools. The completion and preparation of the tool is satisfaction in itself. In the following examples, I will discuss possibilities of tool production and use that arise due to the combination of independent elements based on the new perception of problems and new solution approaches.

Production and use of a spear by *Homo heidelbergensis*

00. Perception basic need (in principle, semi-acute): food
00a. Perception subproblem 1 (in principle, semi-acute): hunt prey
00b. Perception subproblem 2 (in principle, semi-acute): need of spear (tool 1)
00c1.Perception subproblem 3A (semi-acute): need of handaxe to cut down tree (tool 2): quality A
00c1.Perception subproblem 3B (semi-acute): need of handaxe to cut down tree (tool 2): quality B
00d. Perception subproblem 4 (semi-acute): need of flake tool (tool 3) to work wood
0e. Perception subproblem 5 (acute): need of hard hammer stone (tool4) to produce tool 3 and work on tool 2
0f. Perception of subproblem 6 (semi-acute): need of a soft hammer stone (tool 5) for retouch of tool 2

PHASE I: Search for tool 5 (soft hammer stone)

PHASE II: Transport of tool 5 / Search for tool 4 (hard hammer stone)

PHASE III: Transport of tools 4, 5 / Search for raw material for tools 2 and 3

PHASE IV: Production of tool 2 / Use of tool 4 → roughing out of handaxe

PHASE V: Production of tool 2 / Use of tool 5 → thinning

PHASE VI: Production of tool 2 / Use of tool 5 → retouch

00-00f. Perception of basic need, subproblems 1-6 (in principle)
0g. Perception subproblem 7 (acute): secure tools at site

PHASE VII: Transport of tools 2, 4, 5 and raw material to site

PHASE a-z: several other activities (not related, not specified)

00-00b.Perception basic need, subproblems 1-2 (in principle, semi-acute)
0c. Perception subproblem 3 (acute)

PHASE VIII: Search for raw material for tool 1 / Transport of tool 2

00-00b.Perception of basic need, subproblems 1-2 (in principle)
0c. Perception subproblem 3 (acute)
0g. Perception subproblem 7 (acute): secure tools at site

PHASE IX: Transport of tool 2 to site

PHASE a‘-z‘: several other activities (not related, not specified)

00-00b.Perception basic need, subproblems 1-2 (in principle, semi-acute)
0c. Perception subproblem 3 (acute)

PHASE X: Search for raw material for tool 1 / Transport of tool 2

PHASE XI: Production of tool 1 / Use of tool 2 → cut down tree

PHASE XII: Production of tool 1 / Use of tool 2 → roughing out of blank of spear

00-00b. Perception basic need, subproblems 1-2 (in principle, semi-acute)
0c. Perception subproblem 3 (acute)
0g. Perception subproblem 7 (acute): secure tools at site

PHASE XIII: Transport blank 1 and tool 2 to site

PHASE a“-z“: several other activities (not related, not specified)

00-00a.Perception basic need, subproblem 1 (on principle, semi-acute)
00b1.Perception subproblem 2A (semi- acute) : quality A
00b2.Perception subproblem 2B (semi- acute) : quality B
0d-e.Perception subproblem 4-5 (acute)

PHASE XIV: Production of tool 3 / Use of tool 4

PHASE XV: Production of tool 1 / Use of tool 3 → reworking bases of branches

PHASE a“‘-z“‘: several other activities (not related, not specified)

00-00a. Perception basic need, subproblem 1 (in principle, semi-acute)
00b1. Perception subproblem 2A (semi-acute) : quality A
00b2. Perception subproblem 2B (semi-acute) : quality B
0d-e. Perception subproblem 4-5 (acute)

PHASE XVI: Production of tool 3 / Use of tool 4

PHASE XVII: Production of tool 1 / Use of tool 3 → removing bark, reworking form

PHASE a-z: several other activities (not related, not specified)

00-00a.Perception basic need, subproblem 1 (in principle, semi-acute)
00b1. Perception subproblem 2A (semi-acute) : quality A
00b2. Perception subproblem 2B (semi-acute) : quality B
0d-e. Perception subproblem 4-5 (acute)

PHASE XVIII: Production of tool 3 / Use of tool 4

PHASE XIX: Production of tool 1 / Use of tool 3 → reworking form, carving tip

PHASE a-z: several other activities (not related, not specified)

0-0b.Perception basic need, subproblems 1, 2 (semi-acute, acute)
0c. Perception subproblem 3 (semi-acute): need of tool 2 (handaxe) to butcher prey

00f‘.Perception subproblem 6 (semi-acute): need of tool 5 for retouch of tool 2

PHASE XX: Search for prey / Transport of tools 1, 2, 5

PHASE XXI: Satisfaction of need not successful → frustration

00-00c + f. Perception basic need, subproblems 1, 2, 3 and 6 (semi-acute, in principle)
0g. Perception subproblem 7 (acute): secure tools at site

PHASE XXII: Transport of tools 1,2, and 5 to site

PHASE a-z: several other activities (not related, not specified)

0-0b.Perception basic need, subproblems 1, 2 (semi-acute, acute)
0c. Perception subproblem 3 (semi-acute): need of tool 2 (handaxe) to butcher prey
00f‘.Perception subproblem 6 (semi-acute): need of tool 5 to resharpen tool 2

PHASE XXIII: Search for prey / Transport of tools 1, 2, 5

PHASE XXIV: Hunt / Use of tool 1 / Transport of tools 2, 5 → kill animal

PHASE XXV: Butchering prey / Use of tool 2 A → Removing skin

0-0a.Perception basic need, subproblem 1 (acute)
0c1. Perception subproblem 3A (acute): need of tool 2 (handaxe) to break open carcass: quality A
0c2. Perception subproblem 3B (acute): need of tool 2 (handaxe) to break open carcass: quality B
0f. Perception subproblem 6 semi-acute): need of tool 5 (soft hammerstone) to sharpen tool 2

PHASE XXVI: Retouch of tool 2 / Use of tool 5

PHASE XXVII: Butchering prey / Use of tool 2 AB → breaking open and butchering carcass

PHASE XXVIII: Satisfaction of need

00. Perception basic need (semi-acute)
00a-c, f.Perception subproblem 1-3 and 6 (semi-acute, in principle)
0g. Perception subproblem 7 (acute): secure prey and tools 1, 2, 5 at site

PHASE XXIX: Transport of parts of prey and tools 1, 2, 5 to site

PHASE a-z: several other activities (not related, not specified)

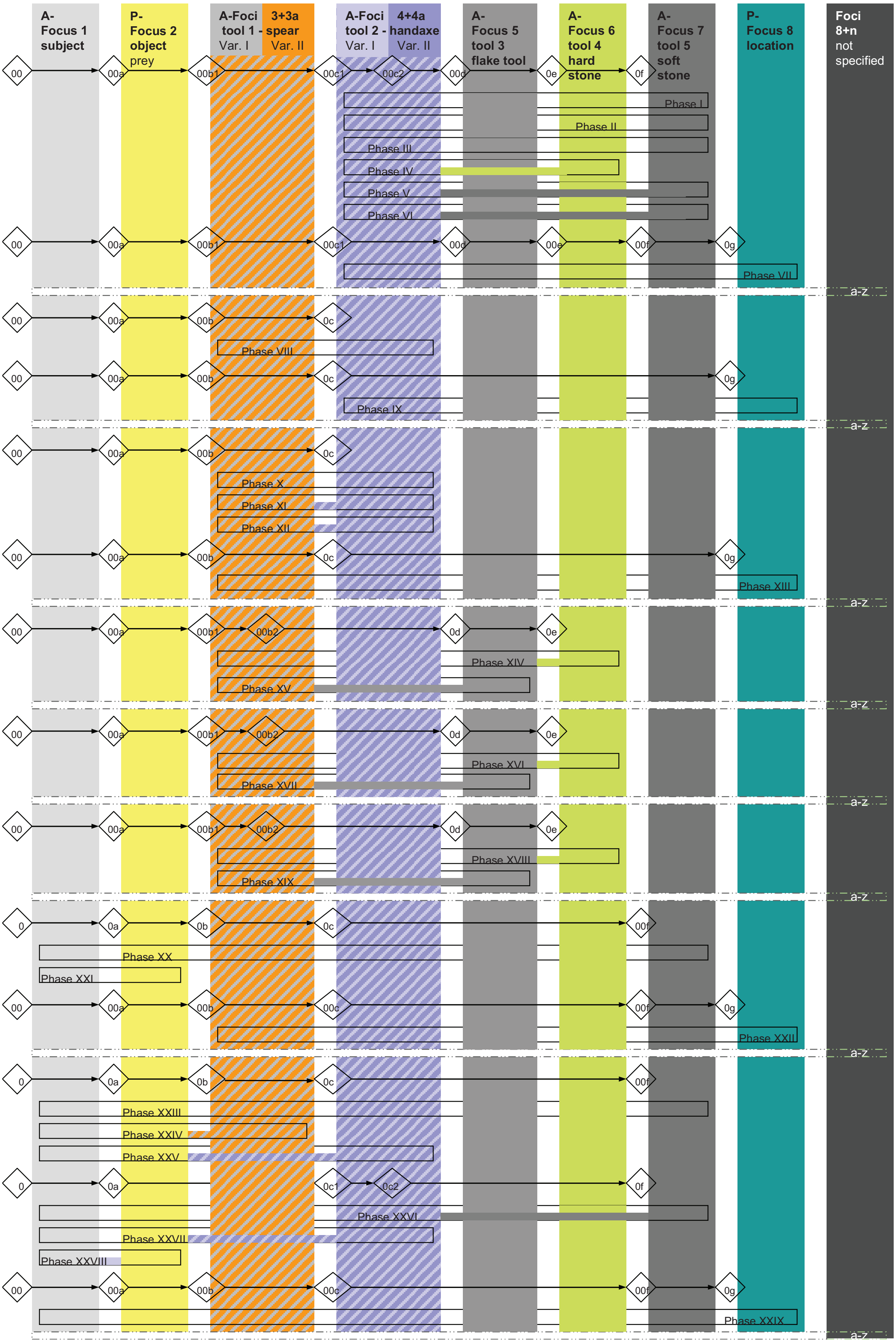


Fig. 77 Cognigram of the production and use of a javelin (simplified).

New Needs: e.g. Aesthetic Behavior

A new category of needs that results from the decoupling of tool behavior and specific need is the occupation with so-called non-functional artifacts. This fuzzy term is primarily used to label aesthetic objects such as art, jewelry, pigments etc. Although these artifacts can have a multitude of functions and take on the role of a tool (comp. Haidle 2003), they do not serve to secure subsistence and are therefore considered non-functional or, for animals, non-adaptive. This label is only valid, if the specified artifact is viewed through economic-colored glasses, where the tool provides a fitness advantage in the fight for survival. Sometimes, animals also use objects, whose function cannot be connected to bodily needs such as subsistence or hygiene or with advantages to reproduction in the broadest sense e.g. with defensive or impressive behavior or learning such behavior through games. The multifaceted game with stones among the Japanese macaques (Huffman 1984; Huffman & Quiatt 1986) or the act of draping plants over their head and shoulders among a number of different types of monkeys (Beck 1980, 75, 78, 104) are examples of this object behavior. The tool character of the objects used in these scenarios is put into question because their functionality is unclear (comp. Chapter 14 and Beck 1980, s.a.). The use of non-adaptive objects and tools among animals has so far only been documented in one short problem-solution distance without specific production phases.

Aside from one solitary jasperite cobble from Makapansgat, South Africa, which resembles a face and which Bednarik (1999) believes can only have been carried into the dolerite cave by hominid action, no artifacts with a primarily symbolic character have been found in the Pliocene. The stone face with three openings, interpreted as eyes and mouth, from the South African australopithecine find site is – especially due to the lack of any additional tool finds – over-interpreted as evidence for early aesthetic behavior. The evidence for aesthetic objects such as minerals, fossils and pigments that were intentionally brought into find sites increases toward the end of the Middle Pleistocene and significantly more so in the Upper Pleistocene. Various pigment finds give evidence to great transport distance, such as the hematite pieces from Hunsgi, India (Paddayya 1977), which were transported more than 25km and were dated to the Acheulian based on the accompanying stone artifacts. A large quantity of different colored pigments was also brought into and partially worked at the Zambian find site Twin Rivers (270,000 – 170,000 years before present). If we extrapolate the 1.6 kg of pigments that were recovered from the excavated portions to the quantity for the entire cave fill, then it is possible to expect circa 57 kg of pigments in the cave (Barham 2002). In the find site 8-B-11 on Sai Island, Sudan, van Peer et al. (2003) identified a number of small flint pebbles with polish produced by use wear and traces of pigments on them together with pieces of red and yellow ochre with smoothed surfaces. The flint may have been used to grind the color pigments into a powder. Sandstone slabs, which are interpreted as rubbing stones for grinding pigments, were found in the layer above the flint pebbles, which dates with absolute date to 223,000 ± 19.000 to 182.000 ± 20.000 years ago and cannot be further differentiated. The slabs may have been flattened and molded using picks, which would represent an example of tertiary tool use.

Another object that has been the subject of much discussion for early aesthetic behavior is the figure from Berekhat Ram, Israel, dated to 280,000 years ago (Marshack 1997; d'Errico & Nowell 2000). The raw form for this artifact is a 3.5cm long piece of tuff stone with a vague human-like form (Fig. 78). Interesting about this piece are the lines etched into the stone to resemble a neck and arms and the possible abrasive traces in the chest area. Although experts do not agree on the details of the etchings or the techniques involved, they do agree that the raw form was intentionally altered and that it resembles a female figure.

Fig. 78 The tuff fragment from Berekhat Ram, Israel with its artificially created human-like form (scale 1cm, from d'Errico & Nowell 2000, Fig. 1)

A similar piece was found in Acheulian layers, dated to 300,000 to 500,000 years, by Lutz Fiedler in Tan-Tan, Morocco (Bednarik 2003). The raw form is made out of 5.8cm long quartzite pebble that has an anthropomorphic form, similar to the figure from Berekhat Ram (Fig. 79). Lines of erosion separate the piece into regions that resemble body parts; artificial horizontal lines, probably made by picking at the stone, complement the natural lines. To secure the diagnostic, a second independent analysis of the piece needs to be carried out, as for the Berekhat Ram figure.

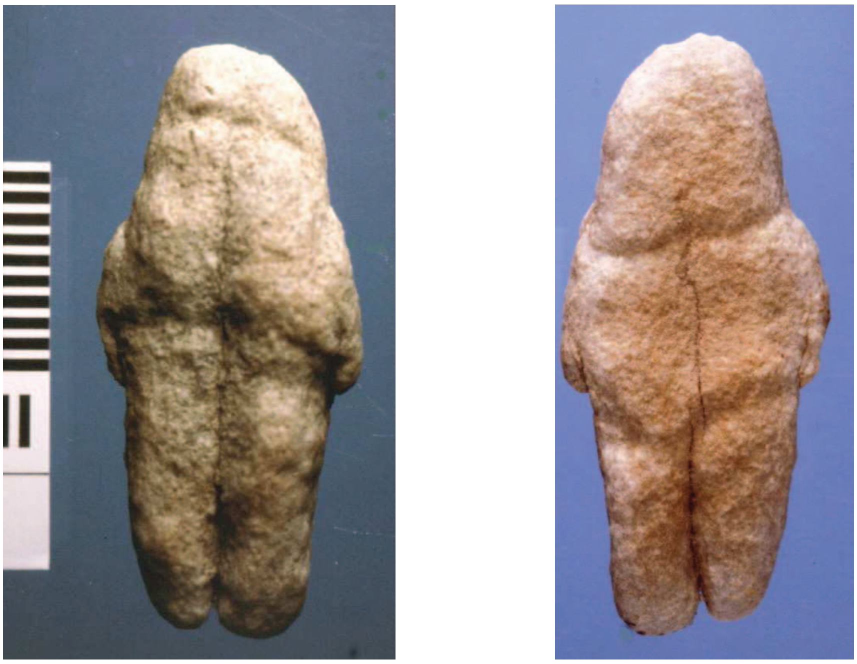


Fig. 79 The anthropomorphic quartzite pebble from Tan-Tan, Morocco, from the front and back, with possible artificial horizontal lines (from Bednarik 2003, Fig. 2 and 3)

Beside partially used chunks of pigments and reworked stones with natural anthropomorphic forms, scratches and scored lines build a third category of early aesthetic expressions. Prominent examples of these are different bone fragments from large mammals from the *Homo heidelbergensis* find site of Bilzingsleben, Thuringia, dated up to 350,000 years ago. The bones showed groups of incised lines, either running radially, as a repetition of three overlapping cuts or as parallel double lines (Mania & Mania 1988; Steguweit 1999). A detailed analysis using a laser microscope found that traces on the four fragments showed that the different groups of lines were each carried out with the same tool and regular incisions. The incisions are not accidental by-products that occurred when the bone fragments were used as a cutting board, but are deliberate cuts whose functions remain unclear (Steguweit 1999; 2003, 124-126).

All of the early artifacts introduced in this chapter have one thing in common: Based on their unclear intention – why and for what purpose where the pieces fashioned? – it is doubtful whether they were intentionally fashioned objects or tools. If we equate the manipulation of aesthetic objects with the use of symbolic tools, then pre-Upper Paleolithic aesthetic expressions are generally rejected because their use in intentional symbolic communication is believed to be improbable. The possible symbolic content of most early artifacts, their codes, are too abstract and the cases of aesthetic objects in the Lower and Middle Paleolithic too rare, to accept them as intentional tools for communication.

We have to differentiate three categories in the communication with symbols in the form of two-dimensional diagrams, three-dimensional forms or even sounds and gestures (Graves-Brown 1995):

a) an icon encodes information based on the recognizable similarity between the symbol and what it represents, e.g. the traffic sign “deer crossing” has a picture of a jumping deer on it.
b) an index associates an object with an sign that identifies it, as a hoof track can be associated with the deer itself.
c) finally, a symbol is an arbitrarily chosen character, such as the word “deer”.

Intentional communication using icons, indices and symbols, e.g. in the form of art objects and jewelry, is deemed to be a marker for modern cognition. The natural animal depictions in the cave and mobile art of the Upper Paleolithic undoubtedly have some meaning and are at the very least seen as iconographic. Contemporaneous abstract characters that frequently show up in combination with these images are also accepted as representatives – although difficult to interpret – conveying information, similarly to the natural depictions. Abstract signs from earlier time periods are generally not attributed such symbolic functions. It was the discovery of an engraved piece of hematite and scores on a bone fragment from the 70,000 year-old middle stone age layers in the South African Blombos Cave (d’Errico et al. 2001; Henshilwood et al. 2002) that made it possible to believe that symbolic behavior may have existed prior to the arrival of anatomically modern humans in Europe. At this find site, these symbols occur within the context of other artifacts, bone tools and pearls made out of shells, that are accepted as markers of modern behavior (Henshilwood et al. 2001; 2004).

At earlier find sites without accompanying markers for modernity, it remains difficult to recognize the use of symbolic tools, which is why “non-functional” and aesthetic objects – or, as in the case of handaxes, aesthetic elements – are denied any intentional meaning. However, if we look at these artifacts from the point of view of decoupling specific problems from the corresponding solution, then new possibilities for interpretation arise. Symbolic communication between people requires a principle agreement on a code between the person sending the signal and the person receiving the signal. This is simplified if a group already uses symbols and signs upon which others can build. A group communication system with symbols cannot be developed or implemented from nothing. A basic set of signs and symbols have to exist, their meaning is slowly diverted from their original intent. These forerunners were created in individual processes and gained their own meaning before the group could use them or similar artifacts as signals. The introduced objects and objects similar to them can be interpreted as artifacts with individual meaning.

In order to prepare an object such as the piece of tuft from Berekhat Ram so that its meaning can be subsequently recognized and accepted from a scientific point of view, it is necessary to handle tools in such a way that is not connected to a specific subsistence problem. An individual discovers the raw material, recognizes the human-like shape of the object and then uses one or more tools to make the form more precise. The tools are not used to produce another tool with a clear function but for a task without a clear basic need that could be satisfied through the use of the new artifact. Satisfaction is achieved by using the tools to produce an object like the Berekhat Ram figurine.

This behavior can be compared to the handling, hugging and carrying around of rocks practiced by Japanese macaques (Huffman 1984; Huffman & Quiatt 1986), where the satisfaction seems to be achieved by the simple handling of objects. In my opinion, these objects can be labeled as tools because they are manipulated in such a way as to achieve psychological satisfaction. The difference between *stone handling* among Japanese macaques and the aesthetic objects lies in the problem-solution distance: In the animal example, the objects are immediately used to satisfy the psychological need that activated the thought and action chain. The aesthetic objects from the Lower Paleolithic seem to have been part of a developing need. Both the development of the need and the satisfaction of the need were long-term processes, which intensified with the continuous manipulation of the object or tool, and include an increase in the meaning and significance of the object.

At the beginning, this type of tool use and preparation occurred on an individual basis. As long as it is limited to isolated cases whose purpose is not manifest in material solutions such as bite-sized pieces of food or driving off competition, general communication symbols cannot develop. The distribution of not-clearly functional tool behavior with a slowly growing need and delayed satisfaction takes time. The semiotic meaning of modern tools is primarily that of an index, e.g. their meaning is derived from their function (Graves-Brown 1995). Tools that are regularly associated with something can function as an index, e.g. to represent the producer(s) or the community that uses them. Distinguishable tool styles, created by dominant production techniques or form preferences, could also function as an index to distinguish one group from another. Intentional production of a tool with a primary index function – e.g. the royal insignia crown, scepter and globus cruciger – cannot be proven for the Paleolithic.

The production of icons that can be recognized by other individuals due to their similarity to the depicted subject is illustrated by the figure from Berekhat Ram and further demonstrated for the figurative reconstructions of the Aurignacian. It remains difficult to determine, whether these figures were intentionally created to aid communication and convey clear informational content or whether they were private tools with a personal meaning, which other people also considered meaningful. An indicator for the latter meaning can be found in the repetitive content found on numerous objects as, for example, in the representation of the lion man figures from the Hohlestein-Stadel in the Lone Valley and the Hohlefels in the Ach Valley by Schelklingen as well as on the adorant-plaque from the Geißenklösterle (Conard 2003). However, even the frequent depictions of body parts such as the vulva scratching or the colored handprints from the Aurignacian do not provide sufficient evidence for a final interpretation as intended symbols for communication

Symbols (see the definition above) are, more so than icons and indices, dependent on a group meaning that goes beyond the individual. Abstract signs can also serve as an individual or common index e.g. to represent the prior presence of a (specific) person. Yet communication of not specifically associated contents with arbitrarily chosen symbols first arose with the written language that developed e.g. in the high cultures of the early Metal Age of the Mediterranean rim and the Near East. However, that does not rule out the possibility that hard to identify forerunners may have existed. The abstract symbols of the Paleolithic could have developed into such forerunners: The transition from purely rhythmic scorings without specific meaning to abstract symbols with individual meaning and finally to arbitrary symbols used for common communication is fluid.

The discussion surrounding early "non-functional" artifacts, which is also linked to questions concerning the symbolic revolution ca. 35,000 years ago and the beginnings of cultural modernity, concentrates on the symbolic content of the tools and their potential for a form of communication (e.g. Klein 1995; Klein & Edgar 2002; Mithen 1996; Mellars 1996; 2005; McBrearty & Brooks 2000; Wadley 2001; d'Errico et al. 2001; d'Errico 2003; d'Errico et al. 2003).

As discussed above, aesthetic tools can also simply have an individual as well as a primary or secondary meaning. This form is to be expected for forerunners of common tools for communication. It is not necessary to develop new tools on a very abstract level, existing instruments can be exapted, i.e. used for new purposes, to serve another function (comp. Gould & Vrba 1982). The prerequisite for the creation of such tools is the decoupling of specific problems and the search for solutions, which makes it possible to recognize and develop novel needs.

Combining Tool Elements: e.g. Hafting

A further consequence of decoupling specific needs and tools develops from the possibility to combine independent units of a chain of operations. Through the dissolution of a thought and action sequence that ranges from a specific problem to a fitting solution, tools can be produced and made available independently and are used together with other tools to satisfy different needs. It is now also possible to combine different sub-units into a combination tool that can solve new problems and can help improve the satisfaction of known needs.

Such combination or composite tools are, for example, hafted cutting or scraping tools with handles and the combination of projectile points and spears (Stordeur 1987). Completely preserved composite tools are rare in archaeological materials, the earliest specimens were recorded for late glacial period wetland find sites such as in Stellmoor in Schleswig-Holstein (Rust 1943; Bratlund 1990) and also from Neolithic lake shore settlements and the Ötzi find (Egg 1992). Yet pieces of composite tools with evidence for the combination of elements are known from the end of the Middle Pleistocene. The oldest-known evidence comes from the brown coal find site Schöningen 12 in Lower Saxony, placed into the Reinsdorf interglacial, therefore probably into oxygen isotope level OIS 11, and dated to between 300,000 and 400,000 years ago. Four tools made from pinewood were recovered, three of these - with lengths of 17, 19.1 and 32.2cm and a maximum diameter of 3.6, 3.9 and 4.2cm – are broken at one end, and the other end shows an incision. Both ends of the fourth tool, only 11.3 cm long, are incised. The regularly shaped notches at the ends of the fragmented branches are interpreted as cleft hafts for sharp-edged stone tools. The excavator and preparator Hartmut Thieme suggests that especially hard and weathered branch fragments may have been specifically targeted as the raw material for these wooden artifacts (Thieme 1999).

Two pieces of birch pitch (Fig. 80) from 80,000 year-old layers from the find site Königsaue in Saxony-Anhalt, show impressions from stone artifacts and their hafting (Mania & Toepfer 1973). These are the first pieces of evidence for the use of a special connective material that combined and secured the elements “handle” and “stone tool” more effectively than regular cleft connections. The origin of the material clearly identified as birch pitch, is not clear (Grünberg et al. 1999). The production of birch pitch involves a smoldering process in an airtight environment during which the birch bark converts to pitch (Weiner 1991). Because this is a very difficult process, the intentional production of the raw materials from the Königsauer find site by Neandertals, as postulated by Koller et al (2001), is subject of much discussion. The alternative is a natural smoldering process, occurring under ideal circumstance such as e.g. during a forest fire. In a number of simple steps that better correspond to the thought-and action chain elements of this time period, individuals could have recognized, searched for and used the glue-like qualities of the sticky clumps.

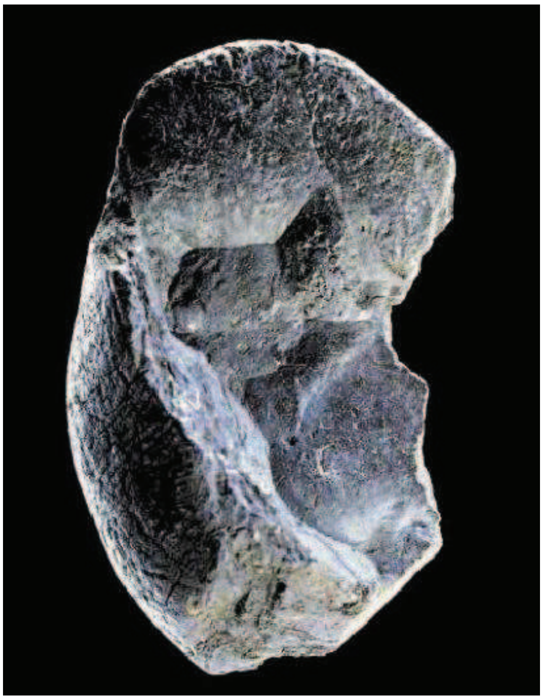


Fig. 80 Piece of birch pitch with impressions of an artifact from Königsaue A (Photo Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, Juraj Lipták).

Another type of glue was used in the late Middle Paleolithic of the Near East. Traces of bitumen were found on two Levallois points that were used as scrapers, from the Middle Paleolithic of the site Umm el Tlel, Syria. Thermoluminescence and C14 accelerator (AMS) date the finds to a minimum age of 36,000 years ago (Boëda et al. 1996). The chemical analyses of naturally occurring bitumen in the region suggest that it must have been heated – possibly during the shafting process. Levallois points in Umm el Tlel were used for cutting different materials and as projectile points (Boëda et al. 1999). The middle fragment of a levallois point was found embedded in the cervical vertebra of a wild donkey found in the 50,000 year old layer IV 3b'1. The size of the reconstructed point suggests that the shaft had to have been between 1.5 to 2 cm thick, therefore, it was probably part of a javelin.

Evidence for shafting comes from contemporary South African find sites such as the Sibudu Cave in KwaZulu-Natal or the Rose Cottage Cave. Marlize Lombard (2005) examined unifacial and bifacial points and fragments from the Middle Stone Age (MSA) from the 51,800 to 61,000 year old layer MOD-SS in the Sibudu Cave. The fracture pattern on the archeological tools, their use wear patterns and the distribution of the different residues imply, in comparison with experimental data, that these tools where shafted. Based on different experimental results, Lombard suggests a combination of the points with wooden shafts from spears or lances with an additional attachment using plant fibers, resin and ochre.

The multiple traces of ochre on the MSA stone tools from the Rose Cottage Cave led Lyn Wadley (2005) to investigate the origins of these traces. The material from Rose Cottage Cave had been washed very thoroughly and was therefore no longer useful for residue analyses. Therefore, Wadley studied the distribution of ochre residue on tools from the contemporary Sibudu Cave. Only 3% of scrapers and 27% of the flakes showed traces of ochre on the working edge while 47% of the flakes, 80% of scrapers and 68% of points showed traces of ochre on the proximal or medial surfaces of the tool. This pattern of distribution suggests that the traces of ochre did not primarily come from working on ochre with the tools, but can possibly be attributed to the use of ochre in the shafting process. Wadley carried out shafting experiments to support her hypothesis that ochre was used as temper for glue and glue mixtures of resin or waxes. Shafts using only resin were brittle and breakable when they dried, while mixtures of resin and ochre or resin, wax and ochre were significantly more robust. She achieved the best and most permanent result when she allowed the glued shaft and tool to dry by low heat near the fire over a period of three to four hours.

Fig. 81 Middle Paleolithic foliated points from the Kleine Ofnet Cave (Collection of the Institute for Pre- and Protohistory and Medieval Archaeology, Department of Early Prehistory and Quaternary Ecology, Eberhard Karls Universität Tübingen. Photo Hilde Jensen).

The late Middle Paleolithic foliated points (Fig. 81), used by different regional groups distributed throughout southeastern Central Europe and Eastern Europe, had multifunctional applications as a cutting tool and a projectile point (Bolus & Rück 2000) similar to the Levallois points from Umm el Tlel, Syria. The carefully worked, bifacially retouched and thinned pieces are examples for the production of elements that were produced independent of a specific problem, that do not simply exist as elements in an active chain consisting of different thought and action processes, but that can also be combined with other elements to make a new tool (Fig. 82).

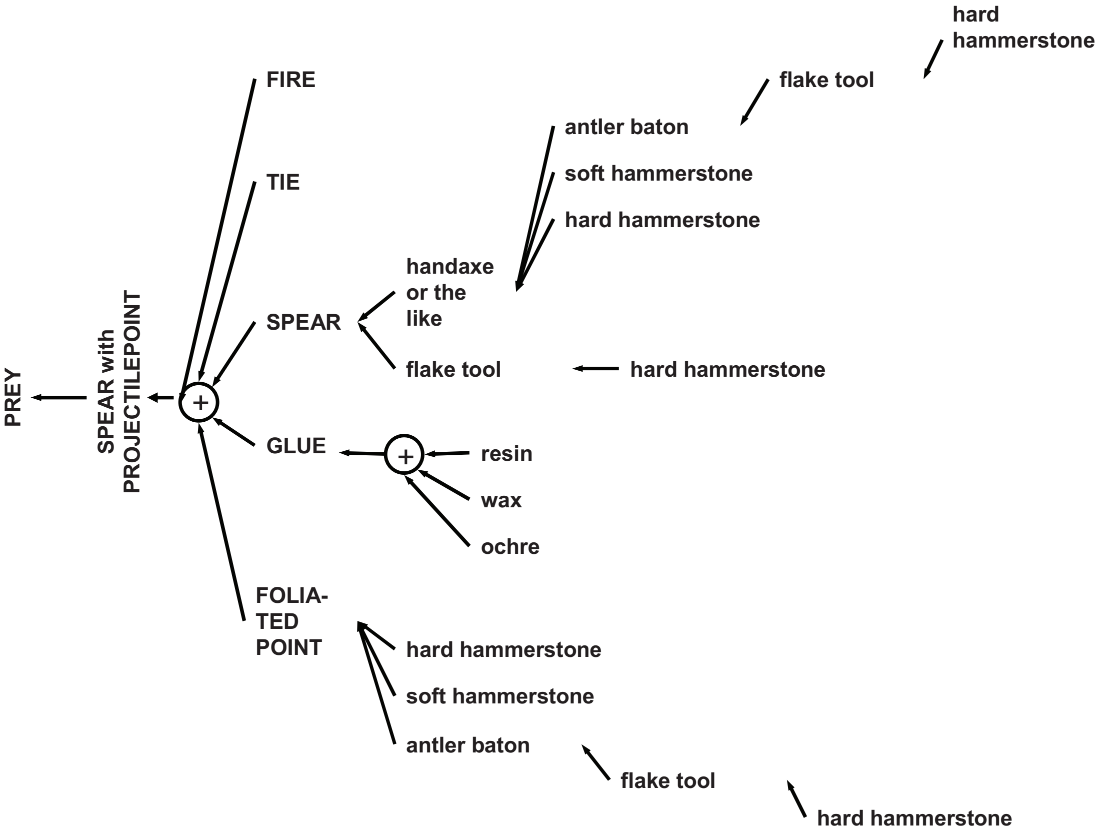


Fig. 82 Possible effective chain for the tools that are required for the production and use of a hunting spear with projectile point. The combination of different elements is marked with a +.

In Chapter 19, I described in detail the great apes' ability to combine similar objects such as boxes, poles or stones into higher stacks, longer fishing rods or more stable anvils and then use them as real or proto-tools. At this point, I introduced the previously rarely used form of additive tool production with an increased potential for problem solving. While the independent elements, which were brought together and then used as one unit were conceived as having the same function – when one box was not enough to reach the hanging fruit another box was added to increase the original effectiveness – it is now possible to combine the different functions of an element to exploit new characteristics and functions. The production of e.g. a spear with projectile point combines the characteristics of a projectile – the ability to kill a larger animal from a distance – with the cutting quality of a stone point or the perforating ability and the robusticity of a bone, antler or ivory awl and the solidity of glue and bindings such as plant fibers or sinews. The function of the individual elements when used on their own in the same (wooden spear without add-ons) or other contexts (point, glue and bindings) is well known.

The important expansion of the problem-solution distance as it is displayed in e.g. shafting, is that the different functions are not simply activated one after another as in the application of e.g. first a perforator and then later a probe for extracting termites or the use of a hammer stone on a stone core to produce a flake for cutting. In composite tools, the different functions of multiple elements work together in one tool with resulting new characteristics. The prerequisite for the combination of composite tools is the existence of elements and tools that are independent of specific needs. A tool is not exclusively used to solve a specific problem, but can also be implemented at a later point in time in more complex contexts with altered problems in connection with the function of additional tools.

An examination of some bone and ivory finds that were interpreted as points by Paola Villa and Francesco d'Errico (2001) showed, that no projectile points made out of organic materials exist for the Lower Paleolithic in Europe at this time. Middle Paleolithic organic points such as the specimens from the Vogelherd (Lonetal), the Grosse Grotte (Achtal), Baden-Wuerttemberg or Salzgitter-Lebenstedt, Lower Saxony (Gaudzinski 1999), are very rare and are primarily dated to the end of this period. Whether these tools functioned as projectile points in composite tools or as awls without a shaft similar to the numerous organic tools from the Châtelperronian layers from Grotte du Renne in Arcy-sur-Cure (d'Errico 2003) needs to be clarified on an individual basis. What Holdoway (1996) still doubted is widely accepted today: Even without clear evidence for organic projectile points, there is no doubt that composite tools and a projectile point technology (Shea 1997) existed prior to the arrival of modern humans in Europe.

In the previous chapters, in addition to the different occurrences of present day animal tool behavior, I described how the problem-solution distance expanded throughout the course of human evolution until the documentation of the decoupling of a specific need and a tool for its satisfaction between 500,000 and 300,000 years ago. The cognitive separation of problem and solution has numerous far-reaching consequences that were already demonstrated using the spear as a tool with an independent function, aesthetic tools for new problem recognition and composite tools for as yet unknown solution approaches. It is possible to present numerous additional details to reconstruct the newest developments, however this would lead to the description of increasingly complex but generally similar processes. The principle of the expansion of the problem-solution distance as a cognitive marker of human evolution has been sufficiently exemplified so that it is not necessary to go into any more details in the outlook.

21 Outlook: Of Tools and Humans, Of Innovations and Traditions

Beside the independence of tools, kept ready and reused in a number of different situations, and the development of aesthetic, symbolic tools and new composite tools, a wide array of new innovative elements in human tool behavior were able to develop due to the decoupling of a specific need from its direct satisfaction. The foundation for an increasing problem-solution distance in more and more complex processes is build upon independent tool elements, the expansion of problem recognition above and beyond immediate basic needs and the ability to imagine a combination of various tools with different functions into one more effective tool. The very complex thought and action chains become manageable when the individual elements can be broken down into smaller thinkable and manageable elements – following the decoupling principle. When we plan the course or chain of action for such a process, these elements are combined into larger sequences; the volume of the individual elements remains small and manageable. The thought and action chains are sorted according to hierarchies; depending on which elements need to be planned or coordinated, different hierarchical levels will be examined.

The momentary maximum problem solution distance is manifested in global industrial production. Take, for example the production of an electric toothbrush and its packaging: Circa 4500 employees in ten countries on three continents are involved in the production (Hoppe 2005), this does not include the supply of raw materials, production of the required machines, tools or energy, logistics and markets. Each person involved is responsible for one tiny element of the thought and action chain involved in the production of the tool, without knowing what the end product looks like or satisfying his own or, at least a recognizable, basic need for an electric toothbrush. Simple things, such as the bread I buy from the bakery down the street, are produced on the basis of dozens of people’s actions, none of whom are aware of my own acute need.

We live in symbiotic relationships with artificial objects that are independent of our specific needs. Their tool characteristic, in close sense of the word – the external application of a freely movable object from the surrounding environment, in order to more efficiently alter the form, position or state of another object, another organism or the user himself, where the user holds or carries the tool prior to its application and is responsible for the correct and effective orientation of the tool (comp. Chapter 14) - is often limited or no longer given. The improved production and use of true tools, in combination with an increasing development of independent elements, leads to a growing production of proto-tools. The world of artifacts, built up out of these true and proto-tools, later also by machines, constitutes the cultural aspect of our environment. It was created, accumulated and developed across millennia. Its elements were assigned function and meaning during their production, yet like elements of the natural world, they also serve as material and theoretical raw materials for the development of additional tools. Tools can be used for activities other than those they were intended for, can be disassembled and recombined or individual parts altered and improved. Besides comprehending that another individual can act intentionally, the decoupling of problem and solution is an important process for the development of the Wagenhebereffekt (car-jack effect) in cultural evolution, defined by Tomasello (2002, comp. Chapter 9).

The expansion of the problem-solution distance is a very slow process (comp. Chapters 18-20) that first appeared in a number of instances of animal tool behavior and continued to develop and increase slowly throughout human evolution. Cognitive steps that can be correlated with relative abrupt and clearly defined features attributed to genetic changes have not been identified. If we search for a physical or genetic basis, we should think of the general expansion of cognitive capacities – such as the yet unknown implications of an increase in brain size or improved genetic activity in the human brain (comp. Chapter 6). Language as the source can be discounted; however, the ability to speak and the cognitive bases of the expansion of the problem-solution distance can have influenced and amplified each other. Generally, we should also discuss whether language could also be viewed as a non-material tool. A multifactorial basis for the expansion of the problem-solution distance seems most likely, whereby it is possible that this development also includes the development of the organization of cognitive processes, exapted or copied from other areas. It is not yet possible to extrapolate a direct correlation with the current theses on the organization of thinking, presented in Chapter 7. Only Bickerton's model (1995) of off-line thinking could possibly correlate to the increased decoupling of an acute problem and its immediate solution. The developmental process in Bickerton's model would need to be significantly altered.

Archaeological models of the development of human thought show a break in cognitive development or postulate an evolutionary leap that took place between 60,000 and 35,000 years ago and is interpreted as the beginning of mental modernity (comp. Chapters 12 and 13). Manifestations of modern human cognition connected to behavioral aspects are language, symbolic and religious actions, planning and reflection and the freedom to combine all areas of knowledge and skills. These behavioral aspects are best identified in non-functional artifacts such as jewelry, art and musical instruments as well as in the Upper Paleolithic blade industry, in bone tools and in burials with burial goods. From the perspective of an increased problem-solution distance, these markers of modern behavior and thought either do not represent specific indicators of cognitive progress or they significantly pre-date the early evidences for increased problem-awareness in the form of aesthetic objects.

The increasing use of tools made out of bone, antler or ivory in the Upper Paleolithic does not represent cognitive innovations as e.g. Steven Mithen (1996, 178) postulated for the use of organic materials. Neither the material, which has previously been used as digging tools in Swartkrans and the hand axes knapped out of bone, instead of rocks, nor the technique developed to carve or scrape with a tool, prepared especially for this task, which can be compared to the tertiary use of tools in e.g. the production of wooden tools, are novel in the time period between 60,000 and 35,000 years before present. Bone tools prepared in this fashion already exist from older African and European find sites such as Broken Hill / Kabwe, Zambia (Barham et al. 2002), Blombos Cave (Henshilwood et al. 2001), Katanda in the Upper Semliki Valley, Zaire (Yellen et al. 1995) or Salzgitter-Lebenstedt, Lower Saxony (Gaudzinski 1999).

From the perspective of the increased problem-solution distance, the youngest cognitive step lies in the combination of independent tool elements into a composite tool, exemplified by the projectile points made out of antler, bone and ivory. This innovation is not limited to organic projectile points but can also be found in shafted tools, e.g. made out of stone and other materials. Early evidence of composite tools dates prior to the critical date – 40,000 years before present (comp. Chapter 20).

The production of blades – long flakes whose length is at least twice as long as its breadth (length-width-index) – is documented for the late Lower Paleolithic as demonstrated by Monigal (2002) in a compilation for the Levant. A marker for modern thinking and behavior is core preparation, characteristic for the Upper Paleolithic, exemplified by the efficient reduction of even flake blanks. The simple knapping techniques of the Lower Paleolithic allowed for a vague predetermination of form and size of the flakes while the Middle Paleolithic Levallois technique, 300,000-250,000 years ago, allowed for much more control of the desired blank based on intensive core-preparation (e.g. Boëda 1990; Boëda et al. 1990; Schlanger 1996; White & Ashton 2003). The three dimensional shaping of the typical shield-shaped core requires a large amount of material debris before it is possible to fashion a small series of target flakes. The Upper Paleolithic blade technologies are characterized by the preparation of at least one striking platform and one flaking surface with one crest (Hahn 1993, 109-130). This type of preparation does not take up as much of the core's volume and allows for serial reduction of increasingly standardized blanks with parallel edges. In contrast to the Levallois technology, the reduction phases in the Upper Paleolithic blade technology are expanded in comparison to the preparation phases.

From the perspective of the problem-solution distance, there are only small differences between the Levallois and Upper Paleolithic blade technologies. Both require a feedback loop in the thought and action chain, similar to the preparation of a carefully worked handaxe (comp. Chapter 19). The products of both technologies are, primarily, independent tool elements that are often produced, finished and combined without a clear specific need. If we compare the cognigrams of both elements from the perspective of the different phases, we do not observe significant differences in the attention foci, or in the phase types (search for raw material and tool, transport, preparation, use), the number of phases or sequence of phases. The innovation can be found in the lowest level of the thought and action chains, in the individual action steps.

Every innovation in tool use does not have to represent a cognitive expansion. Innovation is when a known solution is implemented using new raw materials or when an existing solution is applied to a new problem. It can implement technological changes in production and application, but does not expand the cognitive aspect of the process. Systemic tools such as spear throwers (Stodiek 1993), bows and arrows and needle and thread represent an expansion of the cognitive aspect of the problem-solution distance, above and beyond bone tools and Upper Paleolithic blade technologies. These tool complexes first occurred in the glacial maximum about 18,000 year ago and can be viewed as the further development of composite tools. The combined tools discussed in Chapter 20 consisted of at least one element that could also function independently of the other elements – a javelin also works without the projectile point, Levallois points can be used as cutting tools or in combination with a spear. The elements of systemic tools coordinate with each other and only function correctly when they are used together. During the production of the element “spear thrower”, the builder must consider the throwing spear as another variable; the different elements are connected via a continuous feedback loop.

A phase, which has heretofore not been introduced in the thought and action chains of the production and use of tools that can also be used as elements of another tool, is the production of raw materials and the alteration of the characteristics of raw materials. In animal and most forms of human tool behavior, the raw material for a tool is simply detached and its form altered mechanically by detaching or adding parts or changing its structure, e.g. crumpling leaves. An early form of changing the characteristics of a raw material may be observed in the hardening of wood using fire (Cosner 1956). The charred end of the spruce wood spear from Schöningen 13 II-4 was probably used as a fire stoker or grill spit (Thieme 1999) and there is no evidence of the influence of fire for the Clacton point or the spears from Schöningen. Yet Veil (1991) discusses the possibility that the point of the Lehringen lance was intentionally fire hardened after its production to give it the final touch.

An alteration of the characteristics of raw materials prior to their application has been documented for the Middle Paleolithic in the form of glue, which is heated and probably mixed (comp. Chapter 20). Another improvement of the quality of a raw material prior to working with it, before tool production, is tempering of flint and similar stones. Targeted and controlled heating can significantly improve the fracture qualities of the material. Although evidence for the first isolated occurrences exist for the Middle Paleolithic (e.g. Häußer 1995), systematic tempering comes into fashion from the middle Upper Paleolithic, the Solutrean (Collins 1973) and becomes more and more common starting in the Mesolithic (e.g. Eriksen in print).

While fire hardening and tempering of flint improves the existing characteristics of the raw material, burning ceramics completely alters the characteristics of the raw material clay. The earliest finds of non-intentional ceramics come from Gravettian find sites in Austria and Moravia in the shape of small burned ceramic sculptures (Klíma 1983; 1991; Einwögerer 2000). However, intentional burning of ceramics becomes more common starting with the Neolithic. The raw material must be formed prior to its transformation through heat. This subsequent alteration of the raw material qualities depends on the ability to freely combine independent elements of a thought and action chain. It is not only important to realize that raw material characteristics can principally be changed but also that raw material with specific qualities can be worked mechanically and afterwards the characteristics needed to be able to work with the material can be replaced with others that make the material more useful and stable. The raw material must be viewed as an independent element with its own focus of attention throughout the production process. Elements that are completely independent of the production of specific tools are the production of metal from iron ore, glass and other synthetics.

If we look at the cognitive aspect of the problem-solution distance, it becomes clear that its expansion does not significantly increase with the postulated cognitive revolution between 60,000 – 35,000 years ago, nor does it end with it. It is not possible to determine the prototype of a cognitive modern human using this feature. If we try to determine a key turning point in the development of human tool behavior, then it is most likely to be found in the decoupling of problem and solution. However, this marker does not occur selectively but is the developing result of continuous expansion. It can only be identified retrospectively by observing the consequences resulting from it.

The expansion of the problem-solution distance, more specifically, the decoupling of the search and provision of an independent solution – in the shape of a true tool, a proto-tool or the raw material – from a specific need opens up lots of opportunities for innovation. They influence three factors in particular that support variable tool use (comp. Chapter 17, Figure 27): Breadth of problem recognition, insight into the problem solution and flexibility in the handling of solutions (Fig. 83). These – beside ecological and physical aspects as well as primarily social factors of tolerant and active exchange of information e.g. teaching - make up the group of cognitive factors that allow, limit or cultivate tool use.

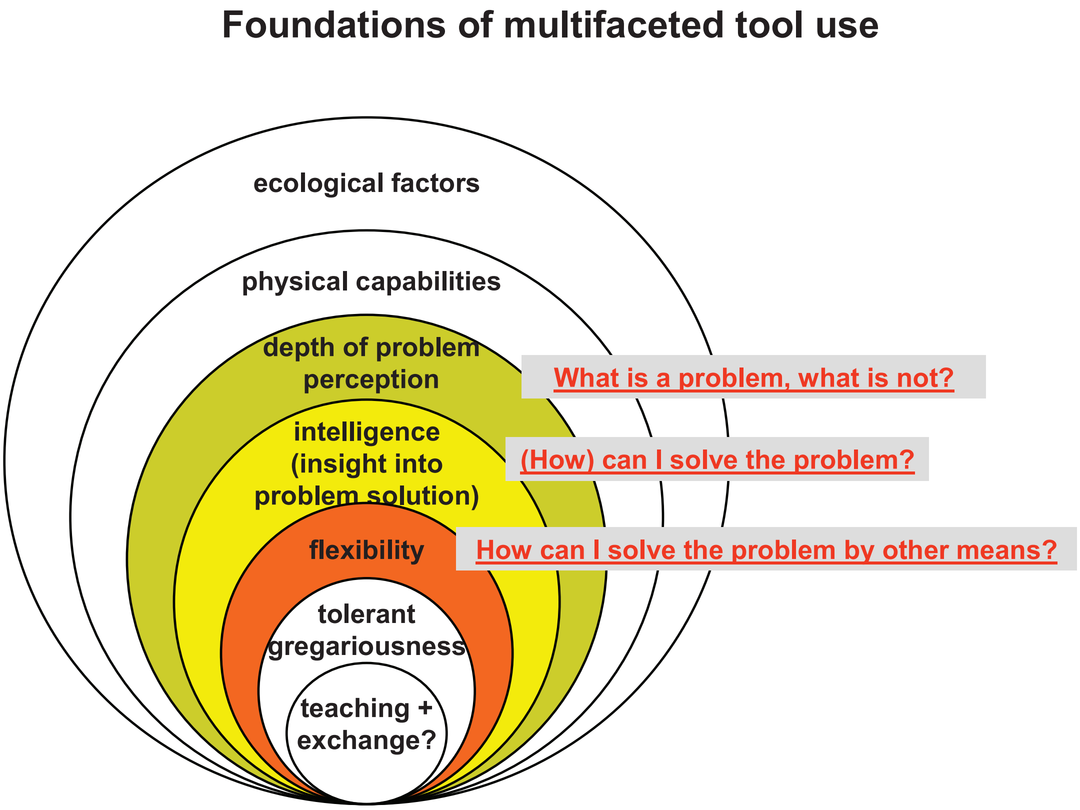


Fig. 83 Factors that support variable tool use: Aspects that are strengthened by decoupling of specific needs and specific solutions are highlighted.

Problems rarely make themselves. They are first and foremost subjective – they must be recognized and accepted by a subject before it is possible to begin searching for a solution. A zebra does not ask itself how it can climb a tree when a lion chases it. This concept is not part of the animal's imagination. Problems can only make themselves known within a species-specific and individual framework of recognition.

The distance between problem and solution makes it possible to "think outside the box" and include tools to solve a task. If we cannot decouple a specific need from its satisfaction, then our problem awareness remains limited to problems that can be solved immediately. The number of situations that are seen as problematic expands, when a subject is able to accept delayed solutions, which requires an advance awareness of problem solutions. If a pool of solutions exists – independent tools, separated from a specific, concrete need – it becomes possible to recognize additional problems in new situations or that they could develop into problems in the near future. It is a very big step to develop a solution, possibly even a tool, for a problem that is not recognized as an immediate basic need and then apply these solutions without the promise of satisfaction. The development of new problem definitions, such as the production of aesthetic objects, becomes significantly simpler when specific solutions in the form of tools already exist and satisfaction is obtained through the application of these tools.

Independent tools challenge the user to try them out – as part of a game, to overcome boredom, or in another problem situation. This effect can be observed in the increased tool behavior among animals in captivity, whose environment included numerous human tools. The basis for this expansion is, however, not fashioned by the animals themselves since humans make the solutions available as part of the environment; Animal solution behavior is still coupled to specific needs and their immediate fulfillment. Hominids, in contrast, have successively expanded their environment, which is a source of problems as well as solutions, through increased decoupling of specific need and immediate satisfaction. This process strengthens itself: New environmental elements such as tools are created, which are then applied to foreign situations or that can be further developed. The independent occurrences of problems and solutions allow for flexible recombination of different problem and solution elements.

The factors influenced by the expansion of the problem solution distance, problem recognition, insight into problem solutions and flexibility, make up the cornerstones of innovation. The alteration of an existing element - e.g. using a different raw material, changing the context or the action chain or expanding on an action chain - and the consequential development of innovative behavior can be attributed to one or multiple individuals, but does not have to result from conscious decisions nor does it have to be recognized as being innovative by that individual. When these alterations of behavior become interesting to the subject and its relations or when the greater population reproduces these, then these behavior variations can be termed innovative. It is advantageous, although not necessary, to recognize intentional behavior in another individual when reproducing its behavior; this can also occur through simple forms of learning such as emulation or stimulus amplification (comp. Chapter 3). The conscious repetition of behavior variations is coupled with a cognitive process. It is not necessary that the consequences of the altered behavior are recognized in advance, but afterwards through a new focus or a shift in focus. The Grevy zebras from the Brookfield zoo are a perfect example for altered behavior (Beck 1980, 154-155; comp. Chapter 18): The game with the feed basket entertains the subject and, at the same time, frightens the other animals. When the subject finally recognizes the side effect, it becomes the actual goal of its actions, which he attempts to reproduce. Therefore the altered behavior becomes an innovation through a shift in focus.

Tradition is a complement and an antagonist of innovation. By making a variation a tradition – by passing it on for multiple generations - it becomes innovation and can be included in the behavioral repertoire of a group. Competing behavioral traditions can handicap or prevent the reproduction and expansion of an innovation. The interaction of traditions and innovations in a group is primarily a social question, not an individual decision, which is mirrored in the factors of tolerant sociability and an active exchange of information (Fig. 83). The different available channels of communication influence the acceptance of an innovation and its transmission within a group either positively or negatively, similar to the size of a group, the social system, decision-making processes in a group and external contacts to members of other groups. Many of these aspects differentiate late in human evolution. The increased potential of social factors in the development of variable tool use exponentiates the effect of the cognitive factors problem recognition, insight into problem solutions and flexibility, so that the development and expansion of tool use and artifact spectrums are slow processes, whose origin is not to be found in a genetic strike of lightning. The meaning of the expansion of the problem-solution distance in the cognitive evolution of human kind and as basis of the creation and expansion of our cultural environment was demonstrated and discussed in detail in this study; a detailed discussion of the development of social factors that influenced the human artifact spectrum is a topic for another study.

Appendix I Animal Tool Behaviour

The next pages contain an as complete compilation of all current known animal tool behaviour as possible. Due to a better clarity the data was tabulated. The table is sorted after animal groups, in which the species are listed alphabetically after their Latin names. The sequence of the different tool behaviours of each species is not in any particular order. The following data was documented, partially coded:

Structure of the Data base

Animal species

Animal group
1 Gastropods
2 Insects
3 Fishes
4 Amphibians
5 Reptiles
6 Birds
7 Mammals
8 Primates
9 Hominids

Situation
1 free and unaffected
2 free and affected
3 free and experiment
4 in captivity
5 in captivity and experiment
6 in captivity and learned

Artefact: Short term for the tool

Description: Information on the condition, production and implementation of the tool, available

Modifications

- 0 none
- 1 severed/detached, broken off
- 2 subtracted e.g. through decortication, defoliation etc.
- 3 addition, e.g. combination
- 4 transformed
- 99 unclear

Function: short description of the tool use context.

RM1: primary raw material

RM 2: complementary or alternative raw material

RM 3: additional complementary or alternative raw material

Literature: References for tool use

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Octopus disgusti (species of Octopus)	1	1	Lid	Shell used as improvised opercula (lid) for snail shell it inhabits.	0	Protection	Shell			Berry pers. com. in Thorpe 1963 in Beck 1980
Octopus vulgaris (Common Octopus)	1	1	Wedge	Stone used as wedge to keep the valves of larger shells open while it eats the meat. Only one incidental observation, similar observation mentioned by Plinius.	0	Subsistence	Stone			Power in Thorpe 1963 in Beck 1980; Power 1857, Plinius Secundus, Wells 1978 in Becker 1993
Tegula brunnea (Species of marine top snail)	1	4	Weight	Stone as counterweight to straighten itself up after the snail was knocked over.	0	Stabilization	Stone			Weldon & Hoffman 1975; Weldon & Hoffman 1975 in Beck 1980; Weldon & Hoffman 1975 in Becker 1993
Tegula funebralis (Species of marine top snail)	1	4	Weight	Stone as counterweight to straighten itself up after the snail was knocked over.	0	Stabilization	Stone			Weldon & Hoffman 1975; Weldon & Hoffman 1975 in Beck 1980; Weldon & Hoffman 1975 in Becker 1993
Xenophora conchyliophora (Species of carrier snail)	1	1	Weight, Disguise	Cements shells etc. to its own shell for stabilization and disguise.	0	Stabilization, Disguise	Shell			Berg 1975 in Beck 1980; Berg 1975 in Becker 1993
Xenophora pallidu (Species of carrier snail)	1	1	Weight, Disguise	Cements shells etc. to its own shell for stabilization and disguise.	0	Stabilization, Disguise	Shell			Berg 1975 in Becker 1993 (Fig. 2)
Alpheus brevirostris (Species of snapping shrimp)	2	1	Shovel	When clearing out its burrow, the snail carries larger pieces of sediment out using its claw. It also takes large pieces and holds them crosswise in order to push out larger quantities of sand.	0	Nest building	Shell	Other objects		Magnus 1967 in Becker 1993
Alpheus californiensis (Californian snapping shrimp)	2	1	Projectile	By popping the claws together, the shrimp directs a target-oriented water spurt toward its prey, thereby stunning it.	0	Subsistence	Water			Volz 1938 in Becker 1993
Ammophila sp. (Sand wasp)	2	1	Hammer	Seals the larvae chamber with small stones and sand by hammering with a stone, twigs, bark, seeds, lumps of soil, insect legs (individual differences in the prevalence).	0	Nest building	Stone	Piece of wood	Seeds	Armbruster 1921, Berland in Thorpe 1963, Brockmann 1977, Evans 1959, Evans & Eberhard 1970, Frisch 1940, Hicks 1932, Hungerford & Williams 1912, Minckiewicz in Thorpe 1963, Molitor 1931, Peckham & Peckham 1898, Rau & Rau 1918 in Beck 1980; s. Becker 1993
Ammophila sp. (Sand wasp)	2	1	Probe	Probe the quality of the seal of a larva chamber (only some individuals?)	99	Nest building	Twig			Brockmann 1977, Hartmann 1905 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Aphaenogaster fulva (Species of myrmicine ant)	2	1	Transport aid	Pieces of leaves, wood, mud and sand are used as a sponge to collect soft or liquid food (honey, fruit or excretions from prey). Tools partially supplied by other worker ants.	99	Subsistence	Leaf	Piece of wood	Other objects	Fellers & Fellers 1976, Morrill 1972 in Beck 1980; s. a. Becker 1993
Aphaenogaster rudis (Species of myrmicine ant)	2	1	Transport aid	Pieces of leaves, wood, mud and sand are used as a sponge to collect soft or liquid food (honey, fruit or excretions from prey). Tools partially supplied by other worker ants. Up to 10 times the yield compared to the yield without tool use.	99	Subsistence	Leaf	Piece of wood	Other objects	Fellers & Fellers 1976, Morrill 1972 in Beck 1980; Fellers & Fellers 1976 in Becker 1993
Aphaenogaster tennesseensis (Species of myrmicine ant)	2	1	Transport aid	Pieces of leaves, wood, mud and sand are used as a sponge to collect soft or liquid food (honey, fruit or excretions from prey). Tools partially supplied by other worker ants.	99	Subsistence	Leaf	Piece of wood	Other objects	Fellers & Fellers 1976, Morrill 1972 in Beck 1980; s. a. Becker 1993
Aphaenogaster treatae (Species of myrmicine ant)	2	1	Transport aid	Pieces of leaves, wood, mud and sand are used as a sponge to collect soft or liquid food (honey, fruit or excretions from prey). Tools partially supplied by other worker ants.	99	Subsistence	Leaf	Piece of wood	Other objects	Fellers & Fellers 1976, Morrill 1972 in Beck 1980; s. a. Becker 1993
Ascalaphus spp. (Larvae of owl fly)	2	1	Disguise	Grains of sand or small pieces of brick on their abdomen. Pieces of brick broken off.	1	Subsistence	Grains of sand	Pieces of brick		Beck 1980
Camponotus senex (South American weaver ant)	2	1	Glue	Ants use their own silk-producing larvae and the sticky secretions they produce to glue together leaves to form nests.	0	Nest building	Larvae			Wheeler 1910, Hölldobler & Wilson 1977 in Beck 1980
Chrysopa slossonae (Larvae of green lacewing)	2	1	Disguise	Plant parts	?	Subsistence	Plant material			Eisner et al. 1978 in Beck 1980
Chrysopa slossonae (Larvae of a species of green lacewing)	2	1	Disguise	Wax from aphids on the abdomen. Disguises them from ants that tend the aphids.	1	Subsistence	Wax shield from the aphids			Eisner et al. 1978 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Conomyrma bicolor (Species of cone/odorous ant)	2	1	Projectile	Throw sand and clumps of soil at competitors for food (three types of myrmicine ants) so that these can only leave their nests to a limited degree.	0	Subsistence	Sand	Clumps of soil		Möglich & Albert 1979 in Becker 1993
Dardanus sp. (Species of crustacean)	2	1	Protection	Sea anemone on its back.	1	Protection	Sea anemone			Ross 1971 in Beck 1980
Dromia sp. (Species of crustacean)	2	1	Disguise	Shells, sea anemones and sponges on their back. Sea anemones and sponges were first procured.	1	Disguise	Shell	Sea anemone	Sponge	Duerden 1905, Meglitsch 1972 in Beck 1980
Euroleon nostras (Antlion, larvae of Ameisenjungfer)	2	1	Projectile	Shots grains of sand from a self-dug pit at its prey.	0	Subsistence	Grains of sand			Alcock 1972 in Becker 1993
Heliocomitus dicax (Larvae)	2	1	Disguise	Grains of sand cemented to its abdomen.	0	Subsistence	Grains of sand			Beck 1980
Lampromyia sp. (Worm lions, larvae of vermileonids)	2	1	Projectile	Shots grains of sand from a self-dug pit at its prey.	0	Subsistence	Grains of sand			Wheeler 1930, de Beer 1948, Skaife 1957, Thompson in Romanes 1892 in Beck 1980
Melia tessellata (Species of crustacean)	2	1	Weapon	Swing the sea anemone in defense and to catch food.	1	Subsistence	Sea anemone			Duerden 1905 in Beck 1980
Melia tessellata (Species of crustacean)	2	1	Weapon	Swing the sea anemone in defense and to catch food.	1	Defense	Sea anemone			Duerden 1905 in Beck 1980
Myrmeleon formicarius (Antlion, larvae of Ameisenjungfer)	2	1	Projectile	Shoots grains of sand from a self-dug pit at its prey.	0	Subsistence	Grains of sand			Wheeler 1930, de Beer 1948, Skaife 1957, Thompson in Romanes 1892 in Beck 1980; Alcock 1972 in Becker 1993
Novomessor albisetosus (Species of myrmicine ant)	2	1	Transport aid	Pieces of leaves, wood, mud and sand are used as a sponge to collect soft or liquid food (honey, fruit or excretions from prey). Transported up to 15 m to the nest.	3	Subsistence	Leaf	Piece of wood	Other objects	McDonald 1984 in Becker 1993
Oecophylla longinoda (Weaver ant)	2	1	Glue	Ants use their own silk-producing larvae and the sticky secretions they produce to glue together leaves to form nests.	0	Nest building	Larvae			Wheeler 1910, Hölldobler & Wilson 1977 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Oecophylla smaragdina (Weaver ant)	2	1	Glue	Ants use their own silk-producing larvae and the sticky secretions they produce to glue together leaves to form nests.	0	Nest building	Larvae			Wheeler 1910, Hölldobler & Wilson 1977 in Beck 1980
Pagurus sp. (Hermit crab)	2	1	Protection	The snail shell is worn to protect the soft body and is replaced by a larger shell when it has grown too small.	0	Protection	Snail shell			Reese 1962, McLean 1974 in Beck 1980
Polydectus cupilifera (Species of crustacean)	2	1	Weapon	Swing the sea anemone in defense and to catch food.	1	Defense	Sea anemone			Duerden 1905 in Beck 1980
Pogonomyrmex badius (Florida harvester ant, species of myrmicine ant)	2	1	Transport aid	Pieces of leaves, wood, mud and sand are used as a sponge to collect soft or liquid food (honey, fruit or excretions from prey). Tools partially supplied by other worker ants. Up to 10 times the yield compared to the yield without tool use. Combination of grains of sand.	3	Subsistence	Leaf	Piece of wood	Other objects	Fellers & Fellers 1976, Morrill 1972 in Beck 1980; s.a. Becker 1993
Polyrachis sp. (Weaver ant)	2	1	Glue	Ants use their own silk-producing larvae and the sticky secretions they produce to glue together leaves to form nests.	0	Nest building	Larvae			Wheeler 1910, Hölldobler & Wilson 1977 in Beck 1980
Salyavata variegata (Larvae (3rd-5th stage) of a kissing bug)	2	1	Bait	Holds a dead termite over the opening of the nest to lure other termites out to eat the bait. The living termites are pulled out with the bait.	0	Subsistence	Termite			McMahan 1983a, 1983b in Becker 1993
Salyavata variegata (Larvae (3rd-5th stage) of a kissing bug)	2	1	Disguise	Camouflage (Odor, Texture) with building material from termite nests, to hide from the termite, their prey.	1?	Subsistence	Termite building materials			McMahan 1983a, 1983b in Becker 1993
Sphex sp. (Sphecoid wasp)	2	1	Hammer	Seals the larvae chamber with small stones and sand by hammering with a stone, twigs, bark, seeds, lumps of soil, insect legs (individual differences in the prevalence).	0	Nest building	Stone	Piece of wood	Seeds	Armbruster 1921, Berland in Thorpe 1963, Brockmann 1977, Evans 1959, Evans & Eberhard 1970, Frisch 1940, Hicks 1932, Hungerford & Williams 1912, Minckiewicz in Thorpe 1963, Molitor 1931, Peckham & Peckham 1898, Rau & Rau 1918, Williston 1892 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Sphex sp. (Sphecoid wasp)	2	1	Probe	Probe the quality of the seal of a larva chamber (only some individuals?)	99	Nest building	Twig			Brockmann 1977, Hartmann 1905 in Beck 1980
Stenorhynchus sp. (Species of crustacean)	2	1	Disguise	Shells, sea anemones and sponges on the back.	1	Disguise	Shell	Sea anemone	Sponge	Duerden 1905, Meglitsch 1972 in Beck 1980
Tetramorium caespitum (Pavement and)	2	1	Projectile	Throws clumps of sand and soil at bees (multiple ants for over an hour) to lure a bee from its earth nest and then kill it.	0	Subsistence	Sand	Clumps of soil		Schultz 1982, Lin 1964-1965 in Becker 1993
Vermileo sp. (Worm lions, larvae of vermileonids)	2	1	Projectile	Shoots grains of sand from a self-dug pit at its prey.	0	Subsistence	Grains of sand			Wheeler 1930, de Beer 1948, Skaife 1957, Thompson in Romanes 1892 in Beck 1980; Alcock 1972 in Becker 1993
Balistes fuscus (Yellow spotted triggerfish)	3	1	Projectile	Blows a jet of water to overturn sea urchin prey in order to get at the less prickly mouth portion and bite the prey.	0	Subsistence	Water			Fricke 1971, 1972 in Becker 1993
Colisa chuna (Honey gurami)	3	1	Projectile	Spits well-aimed jet of water at prey. Not as high (4-5 cm) as archerfish, decreasing with age. Drop salve of circa 10 shots in 2 sec.	0	Subsistence	Water			Beckoff & Dorr 1976, Dill in Beckoff & Dorr 1976, Herald 1956, Lüling 1958, 1963, Milburn & Alexander 1976, Smith 1936, Vierke 1973, Vierke & Lüling 1972 in Beck 1980; Viercke 1971, 1973 in Becker 1993
Colisa chuna (Honey gurami)	3	1	Projectile	Spitting for brood care: Males caring for the brood spit water over the nests of foam, loose eggs are pressed down, the males catch them and glue them down. Females not caring for their own brood show the same behavior as spitting at prey in open nests.	0	Brood care, Subsistence	Water			Vierke 1971, 1973 in Becker 1993
Colisa fasciata (Banded gurami)	3	1	Projectile	Spits well-aimed jet of water at prey. Not as high (4-5 cm) as archerfish, decreasing with age. Drop salve of circa 10 shots in 2 sec.	0	Subsistence	Water			Beckoff & Dorr 1976, Dill in Beckoff & Dorr 1976, Herald 1956, Lüling 1958, 1963, Milburn & Alexander 1976, Smith 1936, Vierke 1973, Vierke & Lüling 1972 in Beck 1980; Viercke 1971, 1973 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Colisa lalia (Dwarf gurami)	3	1	Projectile	Spits well-aimed jet of water at prey. Not as high (4-5 cm) as archerfish, decreasing with age. Drop salve of circa 10 shots in 2 sec.	0	Subsistence	Water			Beckoff & Dorr 1976, Dill in Beckoff & Dorr 1976, Herald 1956, Lüling 1958, 1963, Milburn & Alexander 1976, Smith 1936, Vierke 1973, Vierke & Lüling 1972 in Beck 1980; Viercke 1971, 1973 in Becker 1993
Toxotes chatareus (Archerfish)	3	1	Projectile	Spits well-aimed jet of water at prey.	0	Subsistence	Water			Beckoff & Dorr 1976, Dill in Beckoff & Dorr 1976, Herald 1956, Lüling 1958, 1963, Milburn & Alexander 1976, Smith 1936, Vierke 1973, Vierke & Lüling 1972 in Beck 1980; Schlosser 1764, 1766 in Becker 1993
Toxotes jaculatrix (Archerfish)	3	1	Projectile	Spits well-aimed jet of water at prey.	0	Subsistence	Water			Beckoff & Dorr 1976, Dill in Beckoff & Dorr 1976, Herald 1956, Lüling 1958, 1963, Milburn & Alexander 1976, Smith 1936, Vierke 1973, Vierke & Lüling 1972 in Beck 1980; Schlosser 1764, 1766 in Becker 1993
Trichogaster pectoralis (Snakeskin gurami)	3	1	Projectile	Spits well-aimed jet of water at prey.	0	Subsistence	Water			Viercke 1971 in Becker 1993
Trichogaster trichopterus (Three spot/Blue gurami)	3	1	Projectile	Spits well-aimed jet of water at prey.	0	Subsistence	Water			Beckoff & Dorr 1976, Dill in Beckoff & Dorr 1976, Herald 1956, Lüling 1958, 1963, Milburn & Alexander 1976, Smith 1936, Vierke 1973, Vierke & Lüling 1972 in Beck 1980; Viercke 1971 in Becker 1993
Alectura lathami (Brush turkey)	6	1	Projectile	Drive away a 2m long lace goanna (monitor lizard) by pelting it with sand, stones, and rubbish using the feet.	0	Defense	Stones	Rubbish	Sand	Dow 1980 in Becker 1993
Amazona aestiva (Blue-fronted amazon)	6	4	Scratcher	Holds different objects in its foot to scratch its head, neck, back, throat or side.	99	Personal hygiene	Stick			Blanden in Boswall 1977, 1978 in Beck 1980
Amazona ochcrocephala (Yellow-crowned amazon)	6	4	Container	Scoop up seeds with bell.	0	Game?	Bell			Murphy in Boswall 1983a in Lefebvre et al. 2002
Anodorhynchus hyacinthinus (Hyacinth macaw)	6	4	Pad	Wraps fruit in a leaf or tears off small piece of wood and positions it between the palm nut and upper jaw to prevent the nut from slipping when it is opened.	1	Subsistence	Leaf	Wood		Borsari & Ottoni 2005; Bertagnolio 1994 in Lefebvre et al. 2002

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Aquila verreauxi (African black eagle)	6	1	Projectile	Defense of the nest against invaders by throwing 30-40 cm long stick from a height of circa 20 m.	99	Defense	Stick			Dick & Fenton 1979 in Becker 1993
Ardeola ralloides (Squacco heron)	6	1	Bait	Insects on water to lure fish for their prey (20 min. 16 insects for one fish).	0	Subsistence	Insects			Prytherch in Boswall 1977 in Beck 1980; Prytherch 1980 in Becker 1993; Crous 1994 in Lefebvre et al. 2002
Bradornis microrhynchus (African grey flycatcher)	6	1	Probe	Uses a blade of grass to probe into holes in the veranda to fish for termites.	99	Subsistence	Blade of grass			McNaughton in Boswall (o.J.) in Becker 1993; McNaughton in Boswall 1983b in Lefebvre et al. 2002
Butorides striatus (Striated heron)	6	1	Bait	Baits fish prey using plants (berries, branches, leaves, pieces of bark), animals (insects, grasshoppers, larvae, worms etc.), feathers, and pieces of plastic, cake. Increasingly with age, only 20% without bait. Some bait cropped with beak.	2	Subsistence	Berries	Insects	other objects	Walsh et al. 1985, Higuchi 1986, Boswall (o.J.) in Becker 1993; Higuchi 1986, Keenan 1981, Foxall & Drury 1987, Wood 1986, English 1987 in Lefebvre et al. 2002
Butorides virescens (Green heron)	6	1	Bait	Throws pieces of bread in water to lure fish for prey. Transport bread over some distances. Replace bait that has drifted away. Drive off other bread-hungry birds. Also use small feather, bird feed and mayflies they caught themselves.	0	Subsistence	Bread	Mayflies	other objects	Norris in Boswall 1977, Lovell 1958, Sisson 1974 in Beck 1980; Lovell 1957, Sisson 1974,Keenan 1981, Norris 1975, Boswall (o.J.) in Becker 1993
Cacatua galerita (Sulphur-crested cockatoo)	6	4	Container	Scoops water with a bottle.	0	Game?	Bottle			Longthorp in Boswall 1983a in Lefebvre et al. 2002
Cacatua galerita (Sulphur-crested cockatoo)	6	1	Projectile	Drives of birds of prey by targeting them with leaves and twigs from their seat 4 m high in a tree. Leaves and twigs were cut using the beak.	1	Threat, Defense?	Leaves	Twig		Finch 1982 in Becker 1993
Cacatua sanguinea (Bare-eyed Cockatoo)	6	4	Scratcher	Holds different objects in its foot to scratch its head, neck, back, throat or side.	99	Personal hygiene	Stick	Twig	other elongated objects	Smith 1970, 1971 in Beck 1980
Cacatua sulphurea (Yellow-crested Cockatoo)	6	4	Container	Hold nutshells with its feet to scoop und and drink water.	0	Subsistence?	Nut shell			Smith 1971 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Cacatua sulphurea (Yellow-crested Cockatoo)	6	4	Scratcher	Holds different objects in its foot to scratch its head, neck, back, throat or side.	99	Personal hygiene	Stick	Twig	other elongated objects	Smith 1970, 1971 in Beck 1980
Camarhynchus (Cactospiza) heliobates (Mangrove finch)	6	1	Probe	Twig or something similar to fish for insects. Possibly copied from the species Cactospiza pallida, which regularly uses tools?	1	Subsistence	Twig	other objects		Curio & Kramer 1964 in Beck 1980; Curio & Kramer 1964 in Becker 1993; Curio & Kramer 1964 in Lefebvre et al. 2002
Camarhynchus pallidus (Cactospiza pallida) (Woodpecker finch)	6	1	Digging stick	Thorn, twig, leaf lamina for digging for insects in loose soil.	1	Subsistence	Thorn	Twig	Leaf Lamina	Tebbich et al. 2001
Camarhynchus pallidus (Cactospiza pallida) (Woodpecker finch)	6	1	Probe	Sharp thorn or twig or something similar to fish for insects. Instrument used multiple times at various locations. Broken off and prepared to the right length, excessive pieces removed.	1, 2	Subsistence	Cactus thorn	Twig		Beck in Bowman 1961, Millikan & Bowman 1967, Gifford 1919; Bowman 1961, Lack 1947, 1953, Eibl-Eibesfeldt 1961, 1963, Eibl-Eibesfeldt & Sielmann 1962 in Becker 1993; s.a. in Beck 1980; Millikan & Bowman 1967 in Lefebvre et al. 2002
Camarhynchus pallidus (Geospiza pallida) (Woodpecker finch)	6	1	Scraper	Uses pieces of wood or bark to scrape off epiphytes	99	Subsistence	Piece of wood			Greenhood & Norton 1999 in Lefebvre et al. 2002
Certhidea olivacea (Warbler finch)	6	1	Probe	Probe into a cleft in a tree with a ca. 7 cm long leaf stem, not successful. Copied from species that regularly use tools?	1?	Subsistence	Leaf stem			Hundley 1963 in Beck 1980; Hundley 1963in Becker 1993 Hundley 1963 in Lefebvre et al. 2002
Ceryle rudis (Pied Kingfisher)	6	2	Bait	Throws pieces of bread in water to lure fish for prey.	0	Subsistence	Bread			Root in Boswall 1983a in Lefebvre et al. 2002
Chlamydera cerviniventris (Fawn-breasted bower bird)	6	1	Wedge	Uses a prepared piece of bark (or bark fiber, bundles of dried grass?) to keep its beak open while it paints the bowers and to suck up excessive paint.	1, 3?	Nest building	Bark fibers	Grass		Chisholm 1921, 1971a,1971b in Becker 1993
Chlamydera maculata (Spotted bower bird)	6	1	Wedge	Uses a prepared piece of bark (or bark fiber combined into a small ball of bark, or bundles of dried grass (10 x 6 x 4 mm)) to keep its beak open while it paints the bowers and to suck up excessive paint.	1, 3?	Nest building	Bark fibers	Grass		Chisholm 1921, 1971a,1971b in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Chlamydera nuchalis (Great bower bird)	6	1	Wedge	Uses a prepared piece of bark (or bark fiber combined into a small ball of bark, or bundles of dried grass (10 x 6 x 4 mm)) to keep its beak open while it paints the bowers and to suck up excessive paint.	1, 3?	Nest building	Bark fibers	Grass		Chisholm 1921, 1971a,1971b in Becker 1993
Ciconia ciconia (White stork)	6	1	Sponge	Use moss to soak up water to water the young in the nests.	0	Brood care	Moss			Rekasi 1980 in Lefebvre et al. 2002
Colluricincla harmonica (Gray shrike-thrush)	6	1	Probe	Twigs as probes to fish for insects. Use twigs to probe into bricks until the insects crawl out.	1?	Subsistence	Twig			Richards/Mitchell in Boswall 1977 in Beck 1980; Mitchell 1972 in Becker 1993; Mitchell 19 in Boswall 1977 in Lefebvre et al. 2002
Corcorax melanorhamphus (White-winged chough)	6	1	Projectile, hammer	Throws mollusks or mollusk shells to open other mollusks. In Becker 1993 und Lefebvre et al. 2002 described as hammering	0	Subsistence	Mollusk shell			Hobbs 1971, McDonald in Hobbs 1971 in Beck 1980; Hobbs 1971, McDonald 1970 in Becker 1993; Hobbs 1971 in Lefebvre et al. 2002
Corvus albus (Pied crow)	6	1	Projectile	Drop stones onto ostrich nests in flight.	0	Subsistence	Stone			Brooke 1979 in Becker 1993
Corvus brachyrhynchos (Common crow)	6	1	Hammer	Opens acorns with a stone.	0	Subsistence	Stone			Duvall pers. com. in Boswall 1978 in Beck 1980; Boswall (o.J.) in Becker 1993; Duvall in Boswall 1978 in Lefebvre et al. 2002
Corvus brachyrhynchos (Common crow)	6	1	Probe	Probing with sharpened piece of wood.	1?, 4	Subsistence?	Piece of wood			Caffrey 2000 in Lefebvre et al. 2002
Corvus brachyrhynchos (Common crow)	6	4	Container	Fills plastic cup with water to wet dry food, if it was forgotten. Water source up to 5 m away. Repeatedly. If it spills the water, it goes directly back to the water source, not to the food.	0	Subsistence	Plastic cup			Hess pers. com. 1965 in Beck 1980; Beck 1980; Beck 1980 in Lefebvre et al. 2002
Corvus capensis (Cape crow)	6	1	Projectile	Drop stones onto ostrich nests in flight.	0	Subsistence	Stone			Brooke 1979 in Becker 1993
Corvus caurinus (Northwestern crow)	6	4	Lever	Uses stick to pick peanuts from bamboo.	99	Subsistence	Stick			Jewett in Boswall 1983a in Lefebvre et al. 2002

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Corvus corax (Common raven)	6	1	Projectile	Scared off a breeding Seagull from its nest by dropping a bushel of grass, in order to get at the eggs?	1	Subsistence	Grass			Montevecchi 1978 in Beck 1980; Montevecchi 1978 in Becker 1993
Corvus corax (Common raven)	6	1	Projectile	Drives off intruders to the nest by throwing stones (max. 8 x 8 x 2,5 cm), stones dug up.	1	Defense	Stone			Janes 1976 in Beck 1980; Janes 1976 in Becker 1993
Corvus moneduloides (New Caledonian crow)	6	4	Hook	Hook made out of bent wire	4	Subsistence	Wire			Weir et al. 2002
Corvus moneduloides (New Caledonian crow)	6	2	Probe	Uses leaf stems to fish larvae out of holes in dead wood. Previously removes leafy parts from stem.	1, 2	Subsistence	Leaf			Hunt 2000b
Corvus moneduloides (New Caledonian crow)	6	1	Hook	Twig with a hook end.	1, 2, 4	Subsistence	Twig			Hunt 1996; Hunt + Gray 2004; Orenstein 1972 in Beck 1980; Orenstein 1972 in Becker 1993; Orenstein 1972 , Hunt 1996 in Lefebvre et al. 2002
Corvus moneduloides (New Caledonian crow)	6	1	Probe	Sharp, stepped cutout from a leaf.	1	Subsistence	Pandanus leaf			Hunt 1996; 2000; Hunt + Gray 2003; Orenstein 1972 in Beck 1980; Orenstein 1972 , Hunt 1996 in Lefebvre et al. 2002
Corvus ossifragus (Fish crow)	6	1	Projectile	Scare off a breeding seagull using marsh grass from 3-4 m height, to get at the nests? (Grass was blown away by the wind, therefore, unsuccessful).	99	Subsistence	Grass			Montevecchi 1978 in Beck 1980; Montevecchi 1978 in Becker 1993
Corvus rhipidurus (Fan-tailed raven)	6	2	Hammer	Uses a stone to open the “egg” (ping pong ball, mistaken for an egg)	0	Subsistence	Stone			Andersson 1989 in Lefebvre et al. 2002
Corvus splendens (House crow)	6	1	Probe	Uses leaf to fish ants from a hole.	1?	Subsistence	Leaf			Rajan & Balasubramanian 1989 in Lefebvre et al. 2002
Cyanocitta cristata (Blue jay)	6	4	Rag	Soak strips of paper in water in order to wipe up crumbs in the food bowl.	1, 4	Subsistence	Strips of paper			Jones & Kamil 1973 in Beck 1980; Jones & Kamil 1973 in Lefebvre et al. 2002
Cyanocitta cristata (Blue jay)	6	4	Probe	Fish with torn off strips of paper, blades of grass or other objects for food pellets that are out of reach.	1	Subsistence	Strips of paper	Blade of grass		Jones & Kamil 1973 in Beck 1980; Jones & Kamil 1973 in Lefebvre et al. 2002

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Cyanocorax yncas (Green jay)	6	1	Probe	Use short twigs to fish for insects in dead wood.	1?	Subsistence	Twig			Gayou 1982 in Becker 1993
Cyanocorax yncas (Green jay)	6	1	Lever	Use short twigs as a lever to lift up pieces of bark and get at the insects beneath.	1?	Subsistence	Twig			Gayou 1982 in Becker 1993; Gayou 1982 in Lefebvre et al. 2002
Daphoenositta chrysoptera (Varied sittella)	6	1	Lever	Transport and use of twigs to open insect paths in wood (wood borer grub)	1?	Subsistence	Twig			Green 1972 in Lefebvre et al. 2002
Eclectus roratus (New Guinea eclectus parrot)	6	4	Digging stick	Digging a pit for the nest using a palm stem.	99	Nest building	Palm stem			DeCourcey pers. Com. 1978 in Beck 1980
Euphagus cyanocephalus (Brewer's blackbird))	6	1	Sponge	Dip prey in water to water the young birds in the nest.	0	Brood care	Prey			Koenig 1985 in Lefebvre et al. 2002
Eurypya helias (Sunbittern)	6	1	Bait	Throws maggots in water to lure fish for prey.	0	Subsistence	Maggot			Alders in Boswall 1977 in Beck 1980; Alders in Boswall 1977 in Lefebvre et al. 2002
Falcunculus frontatus (Crested shrike-tit)	6	1	Probe	Twigs as probes to fish for insects. Probes into breaks in the bark with a 5 cm long twig, which it previously broke off of a branch.	1	Subsistence	Twig			Richards in Boswall 1977, Mitchell in Boswall 1977 in Beck 1980; Richards in Boswall (o.J.) in Becker 1993; Richards in Boswall 1977 in Lefebvre et al. 2002
Geospiza conirostris (Large cactus finch)	6	4	Probe	Uses twigs to probe after the animal was held together with a Cactospiza pallida (Woodpecker finch) in a cage for one year.	1	Subsistence	Twig	other objects?		Millikan & Bowman 1967 in Beck 1980
Grallina cyanoleuca (Magpie lark)	6	1	Splint	Splints a hurt leg with feathers and mud? (questionable)	3	Personal hygiene	Feather	Mud		Chisholm 1971a, 1971b in Becker 1993
Grus canadensis (Sandhill crane)	6	4	Rag	Uses towel to dry off after swimming (single individual)	0	Personal hygiene	Towel			Bartlett & Bartlett 1973 in Beck 1980
Haematopus ostralegus (Eurasian oyster catcher)	6	4	Probe	Probe to fish for insects.	1?	Subsistence	Twig			Olney in Boswall 1978 in Beck 1980; Olney in Boswall 1978 in Lefebvre et al. 2002
Haliaeetus leucocephalus (White-bellied sea-eagle)	6	4	Hammer	Uses a stone, which it holds in its claws to break open crickets and scorpions.	0	unclear	Stone			van Lawick-Goodall 1970 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Haliaeetus leucocephalus (White-bellied sea-eagle)	6	4	Hammer	Uses a stick, which it holds in its beak to hit a turtle.	99	unclear	Stick			van Lawick-Goodall 1970 in Beck 1980
Haliaeetus leucocephalus (White-bellied sea-eagle)	6	4	Projectile	Throws stones at crickets, a turtle and a ring to a human (targeted from a distance of max. 60cm).	0	unclear	Stone	Ring		van Lawick-Goodall 1970 in Beck 1980
Hemirostra (Gypoictinia) melanosternon (Black-breasted buzzard)	6	1	Projectile	Drops stones onto Emu eggs (and other birds' eggs such as Australian crane, bustards or ostrich) while in flight, from a height of 3-4 m, in order to open them.	0	Subsistence	Stone			Berney 1905, Campbell & Barnard 1917, Boswall 1977, Chisholm 1954 in Beck 1980; Leitch 1953 in Becker 1993; Debus 1991, Pepper-Edwards & Nottley 1991 in Lefebvre et al. 2002
Kakatoe sp. (Cockatoo)	6	4	Container	Nutshell, to scoop water from an almost empty plate.	0	Subsistence?	Nut shell			Fyleman in Boswall 1977, Fyleman in van Lawick-Goodall 1970 in Beck 1980
Larus fuscus (lesser Black-backed Gull)	6	4	Bait	Throws pieces of bread in water to lure fish for prey.	0	Subsistence	Bread			Sinclair 1984 in Lefebvre et al. 2002
Leiothrix lutea (Red-billed robin)	6	1	Stimulation	Rubs ants into its plumage (active anting) Ants transferred in part to the nesting place. primarily spraying ants) To clean plumage, against parasites? ants combined	3	Stimulation	Ants	other objects		Simmons 1966 in Beck 1980
Leiothrix lutea (Red-billed robin)	6	4	Rag	Dries off with fresh, green leaves after a bath (single individual).	1	Personal hygiene	Leaf			Gibson pers. com. in Boswall 1978 in Beck 1980
Leptoptilos crumeniferus (Marabou)	6	1	Probe	Uses 50 cm long stick with its beak to probe into the cave in a dead tree.	99	Subsistence	Stick			Marshall 1982 in Becker 1993; Marshall 1982 in Lefebvre et al. 2002
Melanerpes (Centurus) uropygialis (Gila woodpecker)	6	4	Sponge	Dips bark into watered honey to transport it to its chicks, after having previously torn off the piece of bark.	1	Subsistence	Bark			Antevs 1948 in Beck 1980; Antevs 1948 in Becker 1993; Antevs 1948 in Lefebvre et al. 2002
Merops ornatus (Rainbow bee eater)	6	1	Digging stick	Digging a pit for the nest using a branch.	99	Nest building	Twig			Chisholm 1954 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Milvus migrans (Black kite)?	6	1	Projectile	Throw smoldering sticks from bush fires onto yet unburned areas in order to scare out small animals with the fire. Although this species is spread throughout nearly the entire old world, this tool behavior has only been observed in Australia.	0	Subsistence	Twig (smoldering)			Lockwood in Boswall 1977 in Beck 1980; Lockwood 1962, Chisholm 1971a, 1971b in Becker 1993
Milvus migrans (Black kite)?	6	2	Bait	Throws bread into a river with its claws, then waits on a nearby branch for fish and crawfish to come. Hunts the crawfish.	0	Subsistence	Bread			Roberts 1982 in Becker 1993; Roberts 1982 in Lefebvre et al. 2002
Neophron percnopterus (Egyptian vulture)	6	1	Projectile	Throws stones without having a specific target when excited, wide spread behavior.	0	Reduces agitation/ excitement	Stone			Alcock 1970 in Becker 1993
Neophron percnopterus (Egyptian vulture)	6	1	Hammer	Stone used to open ostrich eggs (ca. 60-280g) (Beck 50-500g) transported distances from 5,5 to 10m .Thrown from about 1m. Killed lizard.	0	Subsistence	Stone			van Lawick-Goodall & van Lawick-Goodall 1966; Andersson in Van Lawick-Goodall 1970, Sclater in Schaller 1963, Stevenson in Schaller 1973, Meyers in Beck 1980; Alexander 1838 in Becker 1993; van Lawick-Goodall 1970, Iankov 1983 in Lefebvre et al. 2002
Neositta chrysoptera (Varied sittella)	6	1	Probe	4 cm long piece of wood is held in beak and used as a probe to fish for insects. The probe is held with the foot while the insect is eaten. The bird carries the piece of wood in its beak while walking, drops it when it flies off.	1	Subsistence	Splinter of wood			Green 1972 in Beck 1980; Green 1972 in Becker 1993
Nestor notabilis (Kea)	6	4	Container	Cans and cups to scoop water out of larger vessels, play.	0	Game?	Can	Cup		Porter in Boswall 1977 in Beck 1980
Numenius tahitiensis (Bristle-thighed curlew)	6	1	Projectile	Throws stones at eggs to open them.	0	Subsistence	Stone			Marks & Hall 1992 in Lefebvre et al. 2002
Parus caeruleus (Blue tit)	6	1	Probe	Uses a twig to remove nut from the nut dispenser. Probed using 2 cm long twigs, pine needles.	1?	Subsistence	Twig	Pine needle		Coombes pers. com. in Boswall 1977 in Beck 1980; Boswall (o.J.) in Becker 1993; Coombes in Boswall 1977 in Lefebvre et al. 2002
Parus gambeli (Mountain chickadee)	6	1	Lever?	Splinter (wood?) in cleft	99	unclear	Piece of wood?			Gaddis in Boswall 1983b in Lefebvre et al. 2002

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Parus major (Great tit)	6	1	Lever?	Pine needle in cleft.	1?	unclear	Pine needle			Duyck & Duyck 1984 in Lefebvre et al. 2002
Parus palustris (Marsh tit)	6	5	Sponge	Pulled tape from food dispenser (to prohibit stockpiling), which accidentally fell into the feed meal; then flew off with the "full" tape. Repeated frequently, also by a second animal.	1	Subsistence	Tape			Clayton & Jollife 1996 in Lefebvre et al. 2002 Clayton & Jollife 1996
Passeriformes (Sparrows)	6	1	Stimulation	Rubs ants into its plumage (active anting) Ants transferred in part to the nesting place.(Primarily used spraying ant) or ant-equivalents (bugs, onions, beer, cigarette stubs, mothballs). To clean plumage, against parasites? Ants combined	3	Stimulation	Ants	other objects		Simmons 1966, Whitacker 1957, Potter 1970, Southern 1963 in Beck 1980
Phalacrocorax auritus (Double-crested cormorant)	6	1	Extension	Holds one of its own wing feathers in its beak to reach the preen gland and distribute secrete over its plumage. Only one bird (handicapped?) observed, some in captivity.	1	Personal hygiene	Feather			Meyerriecks 1972 in Beck 1980; Meyerriecks 1972 in Becker 1993
Poecile gambeli (Mountain chickadee)	6	1	Probe	5 cm long piece of wood torn off of a dead tree near a cleft in the wood, probed into this cleft with the wood. Transported the wood from tree to tree.	1	Subsistence?	Splinter of wood			Gaddis 1981 in Becker 1993
Probosciger aterrimus (Ara cockatoo)	6	1	Pad	Tore off leaf and placed it between the nut and bill to make sure that the nut does not slip when it is opened.	1	Subsistence	Leaf			Wallace 1869 in Beck 1980; Wallace 1869 in Becker 1993
Probosciger aterrimus (Ara cockatoo)	6	1	Hammer, audio stimulus	Uses a 12 cm long piece of wood to beat against the trunk of a high eucalyptus tree during courtship. Tool previously torn from a dead tree.	1	Attention	Piece of wood			Wood 1984 in Becker 1993
Psittacus erithacus (African grey parrot)	6	4	Scratcher	Holds different objects in its foot to scratch its head, neck, back, throat or side. Bark previously removed from twig.	2	Personal hygiene	Twig	Wire	other elongated objects	Smith 1970, 1971, Ball in Boswall 1977,1978, Campbell in Boswall 1977, 1978, Kruijt in Boswall 1977, 1978, Taylor in Boswall 1977,1978 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Psittacus erithacus (African grey parrot)	6	4	Container	Holds tube in its beak to scoop up water.	0	Game?	Tube			Smith 1971 in Beck 1980; Smith 1971 in Lefebvre et al. 2002
Ptilonorhynchus violaceus (Satin bower bird)	6	1	Wedge	Uses a prepared piece of bark (or bark fiber combined into a small ball of bark, or bundles of dried grass (10 x 6 x 4 mm)) to keep its beak open while it paints the bowers and to suck up excessive paint.	1?, 3, 4	Nest building	Bark fibers	Grass		Chaffer 1931, Gannon 1930, Marshall 1954 in Beck 1980; Marshall 1932, 1954, 1960, Gannon 1930; Nubling 1939 in Becker 1993
Rhinoptynx clamator (Striped owl)	6	4	Rag	Uses dry leaves to wipe bloody remains from the cheeks (single individual)	0	Personal hygiene	Leaf (dry)			Goodman & Fisk 1973 in Beck 1980
Sericulus chrysocephalus (Regent bower bird)	6	1	Wedge	Uses a prepared piece of bark (or bark fiber combined into a small ball of bark, or bundles of dried grass (10 x 6 x 4 mm)) to keep its beak open while it paints the bowers and to suck up excessive paint.	1?, 3, 4	Nest building	Bark fibers	Grass		Chisholm 1921, 1971a,1971b in Becker 1993
Sitta carolinensis (White-breasted nuthatch)	6	1	Lever	Lever made out of bark	1?	Subsistence?	Bark			Mitchell 1993 in Lefebvre et al. 2002
Sitta carolinensis (White-breasted nuthatch)	6	1	Disguise	Rubs insects and other objects on the bark near their nest holes. To keep squirrels away?	99	Nest building	Insects	other objects		Kilham 1968, 1971 in Beck 1980
Sitta pusilla (Brown-headed nuthatch)	6	1	Lever	Tore off elongated piece of bark, carried it in its beak to level another piece of bark and get at insects beneath. Primarily when no pine nuts are available. Carried the tool from tree to tree.	1	Subsistence	Bark			Morse 1968 in Beck 1980; Morse 1968 in Becker 1993; Morse 1968, Pranty 1995 in Lefebvre et al. 2002
Sturnidae (Starling family)	6	1	Stimulation	Rubs ants into its plumage (active anting) Ants transferred in part to the nesting place. Primarily used spraying ant) or ant-equivalents (bugs, onions, beer, cigarette stubs, mothballs). To clean plumage, against parasites? Ants combined	3	Stimulation	Ants	other objects		Simmons 1966 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Turdus merula (Blackbird)	6	1	Digging stick	Clears a snow-covered area with a twig, while searching for food.	99	Subsistence	Twig			Priddey 1977 in Beck 1980; Priddey 1977 in Becker 1993; Priddey 1977 in Lefebvre et al. 2002
Turdus migratorius (Robin)	6	1	Stimulation	Anting its plumage (rubbing feathers with ants)	0	Stimulation	Ants			Potter 1970 in Beck 1980; Potter 1970 in Becker 1993
Turdus migratorius (Robin)	6	1	Digging stick	Digs for ants in a pile of leaves, rubs the ants into its plumage (anting), multiple use of the tool.	99	Subsistence	Twig			Potter 1970 in Beck 1980; Potter 1970 in Becker 1993
Ailuropoda melanoleuca (Giant panda)	7	4	Rag	Uses sod or clumps of earth, held in its front paws, to clean its lower body.	99	Personal hygiene	Grass sod	Soil		Eisenberg & Kleiman 1977 in Beck 1980
Bubalus bubalus (Water buffalo)	7	4	Scratcher	Tore off top rail of a wooden fence (sometimes picked up from the ground), balanced it between the horns and moved it's neck to scratch its back (frequent destruction of the fences).	1	Personal hygiene	Wooden Rail			Grummt 1963, Lau 1965 in Beck 1980
Canis familiaris (Dog, Cockerspaniel)	7	4	Comb	Marbles and other items are placed behind the upper incisors, the matted hair of the paws is pulled through between the lower incisors or tongue and the objects to comb it out (single individual).	0	Personal hygiene	Marble	other objects		Hart in van Lawick-Goodall 1970 in Beck 1980
Capra ircus (Goat)	7	4	Scraper	Uses straw that it holds with its mouth to scratch itself.	0	Personal hygiene	Straw			Huxley in Thorpe 1963 in Beck 1980
Cervus duvauceli (Barasingha, Indian swamp-dwelling deer)	7	1	Jewelry	Grass hung on antlers	0	Attention	Grass			Schaller 1967 in Beck 1980; Schaller 1967 in Becker 1993
Cervus elaphus (Red deer)	7	1	Jewelry	Mud and plants hung on antlers	0	Attention	Mud	Plant materials		Harris & Duff 1970 in Beck 1980
Cervus nanodes (Tule elk, Tule-wapiti)	7	1	Jewelry	Mud and plants hung on antlers	0	Attention	Debris			McCullough 1971 in Beck 1980
Cervus nippon (Sika deer)	7	1	Jewelry	Mud and plants hung on antlers	0	Attention	Mud	Plant materials		Harris & Duff 1970 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Dipodomys deserti (Desert kangaroo rat)	7	1	Projectile	Throws sand at snakes using its hind legs, to drive them away.	0	Defense	Sand			Disney 1955 in Becker 1993
Elaphurus davidianus (Père David's deer)	7	4	Jewelry	Decorate antlers with mud and plants.	0	Attention	Mud	Plant materials		Beck 1980; Heck 1970, Schaller & Hamer 1978, Wemmer and Collins pers. com. 1978, Beck et al. 1978 in Beck 1980; Schaller & Hamer 1978, Heck 1970 in Becker 1993
Elephas maximus (Asian elephant)	7	1	Frond	Tears off a branch, removes some leaves and uses it as a frond to drive off flies (wild and living in captivity). Also using bundles of straw.	1, 2	Personal hygiene	Branch	Bundle of Straw		Hart et al. 2001; Rensch & Altevogt 1954, Darwin 1871, peel 1879 in Beck 1980; peel 1879; Reid 1985 in Becker 1993
Elephas maximus (Asian elephant)	7	4	Scraper	Uses sticks, branches and bamboo to scratch themselves, the rub their bodies or remove leeches from the axel. Tear out a bamboo plant and separate a fitting piece.	1	Personal hygiene	Branch	Stick		Williams in Hall 1973, Williams in van Lawick-Goodall 1970, McKay 1973, peel 1879 in Beck 1980; peel 1879
Elephas maximus (Asian elephant)	7	1	Projectile	Throw stones, earth, branch, grass and dung at humans and other large unknown objects using the trunk (not at other elephants or predatory animals). In the wild and in captivity.	99	Threat?	Stone	Branch	Dung	Kühme 1963a, 1963b in Beck 1980; Beck 1980
Elephas maximus (Asian elephant)	7	4	Cover	Place hay or grass on their back to protect it from insect bites.	99	Personal hygiene	Hay	Grass		Furniss 1879a, 1879b in Beck 1980; Furniss 1879 in Chevalier-Skolnikoff & Liska 1993
Elephas maximus (Asian elephant)	7	4	Lever	Use sticks when working with tree trunks to stop them from rolling away uncontrolled.	99	Work aid	Stick			Williams 1950 in Chevalier-Skolnikoff & Liska 1993
Elephas maximus (Asian elephant)	7	4	Blower	Use air to blow hay off of their backs with their trunks.	0	Personal hygiene	Air			Chevalier & Skolnikoff & Liska 1993
Elephas maximus (Asian elephant)	7	4	Writing instrument	Hold a stick or stone with their trunk and spontaneously use it to draw in the sand.	99	Game	Stick	Stone		Gucwa & Ehrmann 1985 in Chevalier-Skolnikoff & Liska 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Elephas maximus (Asian elephant)	7	1	Powder	Throw or blow water, mud, dust or plants onto their own body (back, side or stomach) and then rub against a tree etc.	0	Personal hygiene	Water	Mud	Soil	McKay 1973 in Beck 1980
Enhydra lutris (Sea otter, Kalan, Californian sea otter)	7	1	Hammer	Uses a stone to break off an abalone. It uses the same stone throughout numerous dives (879 g, oval, granite).	0	Subsistence	Stone			Fisher 1939, Cushing 1939, Cox 1962, Ebert 1968, Houk & Geibel 1974, Kenyon 1969 in Beck 1980; Fisher 1939, Kenyon 1958-1959, 1975, Cox 1962, Ebert 1968, Houk & Geibel 1974 in Becker 1993
Enhydra lutris (Sea otter, Kalan, Californian sea otter)	7	1	Stabilization?	Wraps kelp and sea weed around its body for better buoyancy and stability when taking a long nap on the ocean.	0	Stabilization	sea weed			Fisher 1939, Kenyon 1969, Jones 1961 in Beck 1980
Enhydra lutris (Sea otter, Kalan, Californian sea otter)	7	1	Projectile	Drive of annoying seagulls trying to steal food, by directing a swell of water at them.	0	Defense	Water			Fisher 1939 in Becker 1993
Enhydra lutris (Sea otter, Kalan, Californian sea otter)	7	1	Anvil	Use stone (sometimes sea shells) to open shells, some animals knock shells onto a stone carried on their chest (ca. 13 mm diameter, weight ~460-670g), sometime the same stone is repeatedly used. Aleutians: only young and old individuals.	0	Subsistence	Stone	Shell		Hall & Schaller 1964; van Lawick-Goodall 1970,Fisher 1939, Kenyon 1969, Murie 1940, Wade 1975, Krear in Hall & Schaller 1964, Lensink in Hall & Schaller 1964, Jones 1951 in Beck 1980; Hall & Schaller 1964 in Becker 1993
Enhydra lutris (Sea otter, Kalan, Californian sea otter)	7	4	Hammer	Use different objects to hammer near and in the water basin, also as a game.	0	Game	Various objects			Kenyon 1958-1959, 1975 in Becker 1993
Equus caballus (Horse)	7	4	Digging stick	Remove snow with a stick.	0	Subsistence?	Stick			Campbell in Boswall 1977 in Beck 1980; Campbell 1977 in Becker 1993
Equus caballus (Horse)	7	4	Scraper	Use a stick by holding it with their mouth to scratch their own flank when the tail is tied.	0	Personal hygiene	Stick			Chapman in van Lawick-Goodall 1970 in Beck 1980; Chapman in Goodall 1970 in Becker 1993
Equus grevyi (Grevy zebra)	7	4	Toy	Throws feed basket, which it holds with its teeth. Young male. Later to intimidate two dominant females.	0	Game	Feed basket			Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Loxodonta africana (African elephant)	7	1	Scraper	Take twig is trunk to scratch legs.	99	Personal hygiene	Twig			Douglas-Hamilton & Douglas-Hamilton 1975 in Beck 1980; Douglas-Hamilton & Douglas-Hamilton 1975, Kühme 1962, 1963 in Becker 1993; Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	1	Projectile	Throw earth at rats, dogs and humans with its feet. Wild: throw objects at other elephants in an aggressive game.	0	Threat?	Earth			Grzimek 1956, Kühme 1963a, 1963b in Beck 1980; Grzimek 1969 in Becker 1993; Chevalier & Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	4	Probe	Scratch and clean their ear with grass and plants.	99	Personal hygiene	Grass	Plant materials		Tetlow pers.com. in Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	0	Club	Held a stick with the trunk and hit at humans.	99	Threat, Defense?	Stick			Nabula pers. com. in Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	1	Rag	Clean cuts on the back with bushels of grass held with the trunk.	1	Personal hygiene	Bushel of grass			Douglas-Hamilton & Douglas-Hamilton 1975 in Beck 1980; Douglas-Hamilton & Douglas-Hamilton 1975 in Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	4	Mop	Sweep floor with plants and then places food on the cleared space.	99	Nest building	Plants			Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	4	Probe	Poke into the temporal gland with a twig.	99	Personal hygiene	Twig			Tetlow pers.com. In Chevalier-Skolnikoff & Liska 1993; Laursen 1975 in Beck 1980
Loxodonta africanus (African elephant)	7	1	Projectile	Throw stones, earth, branch, grass and dung at humans and other large unknown objects using the trunk (not at other elephants or predatory animals). In the wild and in captivity.	99	Threat, Defense?	Stone	Branch	Dung	Douglas-Hamilton & Douglas-Hamilton 1975, Kühme 1963a, 1963b in Beck 1980; Beck 1980; Douglas-Hamilton & Douglas-Hamilton 1975, Kühme 1962, 1963 in Becker 1993
Loxodonta africanus (African elephant)	7	1	Bridge	Push down a strong fence with large tree trunks in order to cross it.	1	Locomotion	Tree			Grzimek 1970 in Beck 1980; Grzimek 1969 in Becker 1993
Loxodonta africanus (African elephant)	7	1	Cover	Place branches, trees, grass, and earth on dead elephants, other animals and humans using trunk or front feet (Beck: similar to hiding food, therefore not toll use?). Branches in part broken off.	1	Cover?	Branch	Leaf	Soil	Douglas-Hamilton & Douglas-Hamilton 1975, Grzimek 1956, Kühme 1963a, 1963b, Nicholson 1955, Sikes 1971 in Beck 1980; Chevalier & Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	1	Projectile	Older bulls throw or push younger bulls through fences to push these down and then cross them.	0	Locomotion	Younger animal			Nabula pers. com., Wushe pers. com. in Chevalier-Skolnikoff & Liska 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Loxodonta africanus (African elephant)	7	1	Powder	Throw or blow water, mud, dust or plants onto their own body (back, side or stomach) and then rub against a tree etc.	0	Personal hygiene	Water	Mud	Soil	Sikes 1971 in Beck 1980
Loxodonta africanus (African elephant)	7	1	Frond	Break off branches and swing them against fences and cars.	1	Threat?	Branch			van Lawick-Goodall 1970 in Beck 1980
Loxodonta africanus (African elephant)	7	1	Cover	Cover a dead elephant's wounds with mud.	0	unclear	Mud			Turner in Douglas-Hamilton & Douglas-Hamilton1975 in Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	4	Blower	Blow air with trunk at its own body, clean the ground, or stop a bird from eating.	0	Personal hygiene, game	Air			Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	1	Seal	Seal off holes that were dug during the dry season with chewed bark.	1, 4	unclear	Bark			Gordon 1966 in Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	1	Blockade	Block a new street with piled up branches. Branches broken off.	1, 3	Threat, Defense?	Branch			Nabula pers. com. in Chevalier-Skolnikoff & Liska 1993
Loxodonta africanus (African elephant)	7	4	Frond	Wave a bushel of hay with the trunk or wipe off the side of the head when meeting other elephants or humans.	0	unclear	Hay			Kühme 1963a, 1963b in Beck 1980
Loxodonta africanus (African elephant)	7	4	Fishing rod	Branch in trunk to reach food that is otherwise out of reach.	99	Subsistence	Branch			Rensch & Altevogt 1954, Bierens de Haan 1931 in Beck 1980; Zedtwitz in Rensch & Altevogt 1954 in Chevalier-Skolnikoff & Liska 1993
Micromys minutus (Eurasian harvest mouse)	7	4	Ladder	Place oat grass blade as a ladder on the side of the cage and climb it. Multiple occurances (single individual).	0	Locomotion	Blade of grass			Zimmermann 1952 in Beck 1980; Zimmermann 1952 in Becker 1993
Mungos mungo (Banded mongoose)	7	4	Projectile	Throw stones through their back legs at the model of an ostrich egg (2 individuals, recently caught).	0	Subsistence?	Stone			van Lawick-Goodall 1970 in Beck 1980
Odocoileus virginianus (White-tailed deer)	7	1	Jewelry	Decorate antlers with mud and leaves.	0	Attention	Earth	Leaves		Pruitt 1954 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Orcinus orca (Killer whale)	7	4	Bait	Vomit fish as bait for seagulls, then wait beneath the surface. Multiple animals up to 4 times a day.	0	Subsistence	Fish (vomited)			Mason 2005
Spermophilus beecheyi (Californian ground squirrel)	7	1	Projectile	Throw sand with their front paws at snakes or into holes that could hold snakes to drive these away.	0	Defense	Sand			Owings et al. 1977, Owings & Coss 1977, Coss & Owings 1978, Hennessy & Owings 1978,Rowe & Owings 1978 in Beck 1980; Owings et al. 1977, Owings & Coss 1977 in Becker 1993
Taurotragus oryx (Common Eland)	7	4	Scraper	Throw over post, picked it up between the horns and used it to scratch their back.	1	Personal hygiene	Pole			Anderson pers. com. 1978 in Beck 1980
Thomomys bottae (Botta's pocket gopher)	7	4	Digging stick	Holds stones or hard pieces of food with circa 15 cm diameter in its front paws to dig its nest. Observed 12 times (single individual). Reused the same tool after it was buried.	0	Nest building	Stone	other objects		Katz 1975 in Beck 1980; Katz 1980 in Becker 1993
Tragelaphus strepsiceros (Kudu)	7	4	Jewelry	Hay and mud on the horns.	0	Attention	Hay	Mud		Beck 1980
Tremarctos ornatus (Spectacled bear, Andean bear)	7	4	Club	Knocked down a branch with leaves and fruit from above its cage.	99	Subsistence	Branch			Lang 1974 in Beck 1980
Tremarctos ornatus (Spectacled bear, Andean bear)	7	4	Fishing rod	Fished swimming bread from the water moat with a branch.	99	Subsistence	Branch			Lang 1974 in Beck 1980
Tremarctos ornatus (Spectacled bear, Andean bear)	7	4	Probe	Irritated heron with a branch.	99	Play, exploration	Branch			Lang 1974 in Beck 1980
Tursiops aduncus (Indo-Pacific bottlenose dolphin)	7	4	Scraper	Use tile to scrape seaweed from the side of the tank. A second individual copied this behavior as well.	0	unclear	Tile			Taylor & Saayman 1973 in Beck 1980
Tursiops sp. (Dolphin)	7	1	Nose protection	Place sponge over nose to protect the nose when digging with it for food at the bottom of the sea. So far only observed in females and young animals.	1	Subsistence	Sponge			Krützen et al. 2005

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Ursus (Thalarctos) maritimus (Polar bear)	7	1	Projectile	Throw block of ice or rock onto sleeping walrus or seals (near breathing holes). Broke blocks of ice from the pack ice, licked it into smaller pieces or made it bigger by dipping into the water? Transport up to 6.5 m to the seal's breathing hole.	2	Subsistence	Rock	Block of ice		Harrington 1962, Kiliaan 1974, Perry 1966, Pluta & Beck 1979 in Beck 1980; Kiliaan 1972 in Becker 1993
Ursus (Thalarctos) maritimus (Polar bear)	7	1	Projectile	Stone on trap to trigger it.	0	Protection	Stone			Kiliaan 1974 in Beck 1980; Kiliaan 1972 in Becker 1993
Ursus (Thalarctos) maritimus (Polar bear)	7	4	Projectile	Throw horse femur at other polar bears.	0	Impress, threat?	Bone			Perry 1966 in Beck 1980
Ursus (Thalarctos) maritimus (Polar bear)	7	4	Projectile	Throw aluminum barrels (ca. 7 kg) and tree trunks while standing on its back legs. Playing. Objects were previously transported a number of meters.	0	Game	Barrel	Tree trunk		Beck 1980 (Abb. 2-3)
Ursus arctos (Brown bear)	7	4	High seat	Places a small barrel near the wall of its cage and sat on it in an upright position to beg for food.	0	Attention, subsistence	Barrel			Dathe 1961 in Beck 1980
Alouatta caraya (Black howler monkey)	8	1	Rag	Wipe and cover wound with chewed leaves. For itself and others of its species.	1, 4	Personal hygiene	Leaves			Azara in Carpenter 1934, Buffon in Boulenger 1936, Carpenter 1934 in Beck 1980; Rengger 1830 in Becker 1993
Alouatta seniculus (Venezuelan red howler monkey)	8	1	Projectile	Throws branches, twigs, leaves at pursuers. Branches were first broken off.	1	Threat, Defense?	Branch	Twig	Leaves	Carpenter 1934, Dampier in Carpenter 1934, Anonym in Kortlandt & Kooij 1963, Schultz 1961 in Beck 1980; Carpenter 1934; Dampier 1697, 1705, Hernandez-Camacho & Cooper 1976 in Becker 1993
Alouatta ssp. (Howler monkey)	8	1	"toilet aid"	unclear? A type of toilette paper?	0	Personal hygiene	Twig	Fruit		Chippendale in Koortlandt & Kooij 1963 in Beck 1980
Alouatta villosa (Guatemalan black howler)	8	1	Projectile	Throws branches, twigs, leaves at pursuers. Branches were first broken off.	1	Threat, Defense?	Branch	Twig	Leaves	Carpenter 1934, Dampier in Carpenter 1934, Anonym in Kortlandt & Kooij 1963, Schultz 1961 in Beck 1980; Carpenter 1934; Dampier 1697, 1705, Hernandez-Camacho & Cooper 1976 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Ateles geoffroyi (Geoffroy's Spider monkey)	8	1	Projectile	Throws branches, twigs, leaves and dung at pursuers. Branches were first broken off. Branches in part weight more than 4 kg. Were carried until the victim came closer	1	Threat, Defense?	Branch	Leaves	Dung	Carpenter 1935, Kortlandt & Kooij 1963, Hernandez-Camacho & Cooper 1976, Schultz 1961 in Beck 1980; Carpenter 1935 in Becker 1993
Ateles paniscus (Red-faced spider monkey)	8	1	Projectile	Throws branches, twigs, leaves at pursuers.	1	Threat, Defense?	Branch	Twig	Leaves	Carpenter 1935, Kortlandt & Kooij 1963, Hernandez-Camacho & Cooper 1976, Schultz 1961 in Beck 1980; Carpenter 1935 in Becker 1993
Cebus albifrons (White-fronted capuchin)	8	4	Fishing rod	Fishing for food with different objects such as sticks, clothes, wire, belt, cards, palm fronds, tied up rodents. Preparation of different objects. Crumble together paper prior to use?	1, 4?	Subsistence	Stick	other objects		Bates in Hobhouse 1926, Belt in Romanes 1892, Bierens de Haan 1931, Coopper & Harlow 1961, Cope in Bierens de Haan 1931, Eisentraut 1933, Garner 1892, Harlow 1951, Klüver 1933, 1937, Krieg 1930, Romanes 1892, Warden et al. 1940 in Beck 1980
Cebus albifrons (White-fronted capuchin)	8	1	Hammer	Break open hard-shelled cumare fruits by hitting them against each other.	0	Subsistence	Nut			Terborgh 1983 in Becker 1993
Cebus albifrons trinitatis (White-fronted capuchin)	8	1	Scoop	Use a spoon made out of a leaf to scoop water from holes in trees.	99	Subsistence	Leaf			Phillips 1998
Cebus apella (Tufted capuchin, Apella)	8	4	Lever	Use a stick or spoon as a lever to open a box.	0	Subsistence?, Exploration?	Stick	Spoon		Rengger 1830, Romanes 1892 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	4	Fishing rod	Fishing for food with different objects such as sticks, clothes, wire, belt, cards, palm fronds, tied up rodents. Preparation of different objects. Crumble together paper prior to use?	1, 4?	Subsistence	Stick	other objects		Bates in Hobhouse 1926, Belt in Romanes 1892, Bierens de Haan 1931, Coopper & Harlow 1961, Cope in Bierens de Haan 1931, Eisentraut 1933, Garner 1892, Harlow 1951, Klüver 1933, 1937, Krieg 1930, Romanes 1892, Warden et al. 1940 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	5	Fishing rod	Fishing for food with a sequence of sticks: first a short stick to reach a longer stick to reach food. Up to 8 sticks in a series? Poss. prior training?	99	Subsistence	Stick			Warden et al. 1940 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Cebus apella (Tufted capuchin, Apella)	8	4	Perfume	Rub different intensive smelling substances and objects into their skin (onions, ants, alcohol, perfume, ammonia, orange skins, tobacco).	0	Stimulation?	Onion	Orange peels	other objects	Beck 1980; Fiedler 1957, Hill 1960, 1967, Nolte 1958, Simmons 1966
Cebus apella (Tufted capuchin, Apella)	8	4	Toy	Targeted throwing and catching of a tissue among a group of apes for over an hour. Throwing and catching with hands and tail.	0	Game	Tissue			Moynihan 1976 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	4	Wrap	Bread used as a layer or wrap for overly ripe, sticky bananas to keep the hands clean.	0	Personal hygiene	Bread			Nolte 1958 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	5	Anvil	Open the lock of a box by hitting the box against a wooden block, held in its hand.	0	Subsistence?	Wooden block			Romanes 1892 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	1	Hammer	Open an oyster using another oyster, a palm nut with another nut, fruits (individual observation). With stones, wooden blocks, bones and nut. Open nuts, insects, eggs with stones, wooden blocks, bones and plates. Half wild: open palm nut by hitting it on an anvil with a rock/piece of wood.	0	Subsistence	Oyster	Nut	other objects	Struhsacker & Leland 1977, Eisentraut 1933, Kooij & van Zon 1964, Nolte 1958, Rengger 1830, Vevers & Weiner 1963 u.a. in Beck 1980 ; Visalberghi & Antinucci 1986 in Becker 1993; Fernandes 1991; Izawa & Mizuno 1977 in Fernandes 1991; Ottoni & Mannu 2001
Cebus apella (Tufted capuchin, Apella)	8	1	Projectile	Throw branches (dead and green broken ones) and dung at humans.	1	Threat, Defense?	Branch	Dung		Klein 1974, Hernandez-Camacho & Cooper 1976 in Beck 1980; Klein 1974, Hernandez-Camacho & Cooper 1976 in Becker 1993
Cebus apella (Tufted capuchin, Apella)	8	4	Poking stick	Poke, prod the dog and another monkey with a stick.	99	Threat, Defense?	Stick			Cooper & Harlow 1961, Romanes 1892 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	1	Projectile	Throw different objects at a specific target.	99	Threat, Defense?	Different objects			Romanes 1892 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	5	Probe	Poke into pipes with a stick to get at food, hidden inside.	99	Subsistence	Stick			Harlow 1951, Klüver 1933, 1937 in Beck 1980
Cebus apella (Tufted capuchin, Apella)	8	4	Fishing rod	Throw sticks, belts or tied up rodents at or behind a target to pull these closer.	0	Subsistence	Stick	Belt	Tied up rodent	Bierens de Haan 1931, Klüver 1933, 1937 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Cebus apella (Tufted capuchin, Apella)	8	5	Blade	3-5 strips of bamboo next to a box with peanut butter, covered wit plastic wrap; cutting the wrap to get at the reward.	2, 4	Subsistence	Bamboo			Westergaard & Suomi 1995
Cebus apella (Tufted capuchin, Apella)	8	5	Probe	3 strips of bamboo next to a box with liquid syrup - fluid dip; use probe to extract syrup.	2, 4	Subsistence	Bamboo			Westergaard & Suomi 1995
Cebus apella (Tufted capuchin, Apella)	8	1	Club	Uses stick or other objects to hit snakes, humans and other monkeys.	0	Threat, Defense	Stick	other objects		Chippendale in Koortlandt &Kooij 1963, Cooper & Harlow 1961, Romanes 1892, Anonym in Koorlandt & Kooij 1963 in Beck 1980
Cebus apella apella (Tufted capuchin, Apella)	8	1	Lever	Use other oyster shells as levers to open an oyster shell.	0	Subsistence	Oyster shell			Fernandes 1991
Cebus capucinus (imitator) (White-headed capuchin)	8	1	Projectile	Drop dead branches on pursuers, dead branch broken or bitten off using hands, feet, tail or mouth. Also, other objects such as palm nuts.	1	Threat, Defense?	Branch	Palm nut	Debris	Baldwin & Baldwin 1977, Oppenheimer 1973, 1977 in Beck 1980; Kaufmann 1962, Oppenheimer 1973, 1977 in Becker 1993; Chevalier-Skolnikoff 1990
Cebus capucinus (White-headed capuchin)	8	4	Projectile	Target food hanging higher up, throw a stick to get it down.	99	Subsistence	Small stick			Bierens de Haan 1931 in Beck 1980
Cebus capucinus (White-headed capuchin)	8	4	Perfume	Rub intense smelling substances such as onions, ants, alcohol, perfume, ammonia, and orange peals, onto their body.	0	Stimulation?	Onion	Orange peels	other objects	Beck 1980; Fiedler 1957, Hill 1960, 1967, Nolte 1958, Simmons 1966
Cebus capucinus (White-headed capuchin)	8	1	Club	Use stick to club a snake. Club mother or other animals with a broken off stick.	1	Defense	Stick			Boinski 1988 in Becker 1993; Chevalier-Skolnikoff 1990
Cebus capucinus (White-headed capuchin)	8	4	Fishing rod	Fish for food with different objects such as sticks, clothing, wire, belt, cards, palm stems, tied up rodents. Separation of different objects. Ball up paper before using it.	1, 4?	Subsistence	Stick	other objects		Bates in Hobhouse 1926, Belt in Romanes 1892, Bierens de Haan 1931, Coopper & Harlow 1961, Cope in Bierens de Haan 1931, Eisentraut 1933, Garner 1892, Harlow 1951, Klüver 1933, 1937, Krieg 1930, Romanes 1892, Warden et al. 1940 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Cebus capucinus (White-headed capuchin)	8	4	Hammer	Break open nuts, insects, eggs using stones, pieces of wood or plates.	0	Subsistence	Stone	Piece of wood	other objects	Bierens de Haan 1931, Eisentraut 1933, Klüver 1933, Kooij & van Zon 1964, Matschie in Armbruster 1921, Nolte 1958, Rengger 1830, Romanes 1892, Tobias 1965, Vevers & Weiner 1963 in Beck 1980
Cebus capucinus (White-headed capuchin)	8	4	Fishing rod	Throw sticks, belts or tied up rodents at or behind a target to pull these closer.	0	Subsistence	Stick	Belt	Tied up rodent	Bierens de Haan 1931, Klüver 1933, 1937 in Beck 1980
Cebus capucinus (White-headed capuchin)	8	1	Hammer	Break open oysters with a stone. Careful: Repot by Dampier from de Buffon (o.J. in Becker 1993) false, Dampier did not write this!	0	Subsistence	Stone			Dampier in Hill 1960, Wafer in Romanes 1892 in Beck 1980; Dampier 1697, 1705, de Buffon (o.J.) in Becker 1993
Cebus capucinus (White-headed capuchin)	8	5	Fishing rod	Fishing for food with a sequence of sticks: first a short stick to reach a longer stick to reach food. Up to 8 sticks in a series? Poss. prior training?	0	Subsistence	Stick			Warden et al. 1940 in Beck 1980
Cebus capucinus imitator (White-headed capuchin)	8	1	Poking stick	Poke fellow monkeys with a dead branch. Game.	0	Game	Stick			Chevalier-Skolnikoff 1990
Cebus capucinus imitator (White-headed capuchin)	8	1	Projectile	Break off and drop branches onto Ateles geoffroyi as part of a game.	1	Game	Stick			Chevalier-Skolnikoff 1990
Cebus capucinus imitator (White-headed capuchin)	8	1	Probe	Walk down branch with stick, probe for insects in tree hole, lick stick.	99	Subsistence	Stick			Chevalier-Skolnikoff 1990
Cebus capucinus imitator (White-headed capuchin)	8	1	Projectile	Throw dead branch at Pekaris.	0	Threat	Stick			Chevalier-Skolnikoff 1990
Cebus nigrivittatus (olivaceus) (Weeper capuchin)	8	4	Hammer	Use stone to open a Palm nut.	0	Subsistence	Stone			Mittermeier pers. Com. 1979, film by Esar in Beck 1980
Cebus ssp. (Capuchin monkey)	8	1	Probe	Break off and decorticate twig to probe under the bark of trees for insects.	1, 2	Subsistence	Twig			Jay 1968 in Becker 1993
Cebus ssp. (Capuchin monkey)	8	5	Ladder	Stick placed upright, leaned against the wall or multiple boxes stacked as a ladder to reach high-hanging food.	99	Subsistence	Stick	Box		Bierens de Haan 1931, Harlow 1951 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Cebus ssp. (Capuchin monkey)	8	4	Bait	Pieces of bread strewn to attract ducks to kill and eat them. Learned from watching their owner feed birds?	99	Subsistence	Bread			Boulenger 1936, Belt in Romanes 1892 in Beck 1980
Cebus ssp. (Capuchin monkey)	8	5	Club	Knock down food.	99	Subsistence	Stick			Bierens de Haan 1931, Klüver 1933, 1937, Harlow 1951 in Beck 1980
Cebus ssp. (Capuchin monkey)	8	6	Blade	Uncontrolled flake production; cutting plastic wrap, cutting meat from bone, produced with hard blow, bipolar, anvil and throwing techniques.	1	Subsistence	Stone			Westergaard & Suomi 1994, Westergaard 1995
Cercocebus galeritus (Tana River mangabey)	8	4	Fishing rod	Fish for food using a stick.	99	Subsistence	Stick			Guillaume & Meyerson 1934 in Beck 1980
Cercocebus ssp (Mangabey)	8	1	Digging stick	Broaden the entrance to underground insect nests using a stick.	99	Subsistence	Stick			Jobaert in Kortlandt & Kooij 1963 in Beck 1980
Cercocebus ssp. (Mangabey)	8	4	Projectile	Throw objects; unclear circumstances.	99	unclear	Objects			Anonym in Kortlandt & Kooij 1963 in Beck 1980
Cercopithecus sabaeus (Green monkey)	8	4	Container	Used peanut shell halve to carry water. One day later, two other animals in the same cage repeated the observed behavior.	0	Subsistence	Peanut shells			Lombardi pers. com. 1973 in Beck 1980
Cercopithecus ssp. (Guenons)	8	4	Bait	Use bread to bait a dog.	0	unclear	Bread			van Lawick-Goodall 1970 in Beck 1980
Cercopithecus ssp. (Guenons)	8	1	Projectile	Drop or throw branches on/at humans.	99	Threat, Defense?	Branch			Kortlandt & Kooij 1963 in Beck 1980
Cercopithecus ssp. (Guenons)	8	1	Projectile	Throw sand and gravel at humans.	0	Threat, Defense?	Sand	Gravel		Kortlandt & Kooij 1963 in Beck 1980
Colobus (Piliocolobus) badius (Western red colobus)	8	1	Projectile	Drop dead branches and twigs (broken off) on humans. Four adult males in 2000 hours of observation, infrequent.	1	Threat, Defense?	Branch	Twig		Struhsacker 1975 in Beck 1980; Struhsacker 1975 in Becker 1993
Colobus (Piliocolobus) badius (Western red colobus)	8	1	Projectile	Throw dead branches and twigs (broken off) at other colobus monkeys. Not very frequent.	1	Threat, Defense?	Branch	Twig		Struhsacker 1975 in Beck 1980; Struhsacker 1975 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Colobus ssp. (Colobus)	8	1	Digging stick	Broaden the entrance to underground insect nests using a stick.	99	Subsistence	Stick			Jobaert in Kortlandt & Kooij 1963 in Beck 1980
Colubus ssp. (Colobus)	8	1	Rag?	Medicated pad - wipe off bodily fluids? Clean wounds?	99	Personal hygiene	Leaf			Anonym in Kortlandt & Kooij 1963 in Beck 1980
Erythrocebus patas (Patas monkey)	8	4	Fishing rod	Use stick to fish for food that was placed out of reach. In experiments, this tool use was adapted to different situations.	99	Subsistence	Stick			Gatinot 1974 in Beck 1980
Erythrocebus patas (Patas monkey)	8	1	Projectile	Drop sticks, stones and other objects on passing ships.	99	Threat, Defense?	Stick	Stone	other objects	Boulenger 1936 in Beck 1980
Erythrocebus patas (Patas monkey)	8	1	Projectile	Throw rocks at humans.	0	Threat, Defense?	Stone			De la Brue in Jennison 1927, de la Brue in Kortlandt & Kooij 1963, Anonym in Kortlandt & Kooij 1963 in Beck 1980
Lagothrix lagothrica (Brown woolly monkey)	8	1	Projectile	Throw their own dung and broken branches at pursuers. Accidental?	99	Threat, Defense	Dung	Branch		Hernandez-Camacho & Cooper 1976 in Beck 1980; Hernandez-Camacho & Cooper 1976, Klein 1974 in Becker 1993
Macaca fascicularis (Crab-eating macaque)	8	5	Fishing rod	Fish for out-of-reach foods using sticks, rags, rope and wire.	99	Subsistence	Stick	Fabric	other objects	Hobhouse 1926, Klüver 1937, Shepherd 1910, Verlaine & Gallis in Spence 1937, Verlaine & Gallis in Hooton 1942, Shurcliff et al. 1971, Warden et al. 1940, Nellman & Trendelenburg 1926, Descher & Trendelenburg 1927, Watson 1908, Yerkes 1916 in Beck 1980
Macaca fascicularis (Crab-eating macaque)	8	1	Hammer	Open oysters using a stone. Stone transported up to 75m.	0	Subsistence	Stone			Carpenter 1887 in Beck 1980; Carpenter 1887 in Becker 1993
Macaca fascicularis (Crab-eating macaque)	8	4	Hammer	Hammer nails using a stick and hammer. Not trained but observed from handymen.	99	Game?	Stick	Hammer		Yerkes 1916 in Beck 1980
Macaca fascicularis (Crab-eating macaque)	8	4	Rag	Use leaves to rub clean objects that can also be eaten.	99	Subsistence	Leaf			Chiang 1967; Chiang 1967 in Beck 1980; Chiang 1967 in Becker 1993
Macaca fuscata (Japanese macaque)	8	2	Toy	Stone handling: Stones, 2-730g, 11x11x11mm^3 to 110x110x70mm^3, 30s-20min). Collected, picked up, carried, rolled in hands, rubbed, held in arms. Oregon: Rolled when walking backwards, Carry a stick.	0	Game	Stone	Stick		Eaton 1972; Huffman & Quiatt 1986; Huffmann 1984, 1996; Whiten et al. 1999

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Macaca fuscata (Japanese macaque)	8	4	High seat	Snowball, 60 cm diameter. Used as a high seat. Used as a lookout from the group. Also observed for the free living Shiga-kogen group - snowball.	4	Game	Snow			Eaton 1972; Huffmann 1984
Macaca fuscata (Japanese macaque)	8	4	Toy	Use the branch as a crutch, push it across the ground, running.	0	Game	Stick			Eaton 1972
Macaca fuscata (Japanese macaque)	8	4	Stimulation	Carry young animals during rutting season to stimulate the penis.	0	Stimulation	Young animal			Kawai 1959 in Beck 1980
Macaca fuscata (Japanese macaque)	8	4	Toy	Fasten staff to the cage, swing from the staff.	0	Game, Attention?	Staff			Candland et al. 1978 in Beck 1980
Macaca fuscata (Japanese macaque)	8	4	Social stimulus	Approach other male with young animal as peacekeeper. Agonistic buffering	0	Protection	Young animal			Kawai 1959 in Beck 1980
Macaca fuscata (Japanese macaque)	8	1	Projectile	(Pluck? and) Drop pine cones on humans.	1?	Threat, Defense	Pine cone			Kinnaman in Hall 1963 in Beck 1980
Macaca fuscata (Japanese macaque)	8	4	Ladder	Use post to help stand upright and climb up to lick something off of the wall. 3 young females.	0	Subsistence?	Pole			Machida 1990 in Ueno & Fujita 1998
Macaca fuscata (Japanese macaque)	8	4	Projectile	Individual male throws stones around to impress and frighten. One or two stones, thrown over its shoulder.	0	Attention	Stone			Eaton 1972; Eaton 1972 in Beck 1980
Macaca mulatta (Rhesus macaque)	8	4	Toy	Pieces of fabric wrapped around its head.	0	Game	Fabric			Watson 1908 in Beck 1980
Macaca mulatta (Rhesus macaque)	8	5	Fishing rod	Uses sticks, rags, rope and wire to fish for food that is out of reach. Also fish for longer stick to reach food. Partial preparation of tools.	2?, 4?	Subsistence	Stick	Fabric	other objects	Hobhouse 1926, Klüver 1937, Shepherd 1910, Verlaine & Gallis in Spence 1937, Verlaine & Gallis in Hooton 1942, Shurcliff et al. 1971, Warden et al. 1940, Nellman & Trendelenburg 1926, Descher & Trendelenburg 1927, Watson 1908, Yerkes 1916 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Macaca mulatta (Rhesus macaque)	8	4	Fishing rod	Food outside of cage. Tail of young animal that fits through the cage bars is held. As soon as it has filled its cheeks with food it is pulled back and the food is taken away.	0	Subsistence	Young animal			Watson 1908 in Beck 1980
Macaca mulatta (Rhesus macaque)	8	1	Projectile	Throw roof shingles at police men following them (previously loosened?).	1?	Threat, Defense	Roof shingle			Boulenger 1936 in Beck 1980
Macaca mulatta (Rhesus macaque)	8	4	Projectile	Throw staff or stick at the food container before food is taken out.	99	Subsistence	Stick	Staff		Beck 1976a, Hobhouse 1926 in Beck 1980
Macaca mulatta (Rhesus macaque)	8	1	Projectile	Rolled large stone over a cliff onto humans below. Stone previously dug up.	1	Threat, Defense?	Staff			Hingston1920 in Becker 1993
Macaca nemestrina (Southern Pig-tailed macaque)	8	4	Projectile	Aim and throw staff or stick at the food container before food is taken out.	99	Subsistence	Stick	Staff		Beck 1976a, Hobhouse 1926 in Beck 1980
Macaca nemestrina (Southern Pig-tailed macaque)	8	5	Fishing rod	Use staff to reach at out-of-reach food container. No prior training, after 8 hours first success.	99	Subsistence	Staff			Beck 1976a in Beck 1980
Macaca nemestrina (Southern Pig-tailed macaque)	8	4	Toy	Branch and pieces of wood carried around, stuck into fence and sat on.	99	Game	Branch	Piece of wood		Bernstein pers. com. 1973 in Beck 1980
Macaca nemestrina (Southern Pig-tailed macaque)	8	4	Probe	Use wire to probe after a mouse in its hole. Smell the probe afterwards.	0	Exploration	Wire			Beck 1980
Macaca nemestrina (Southern Pig-tailed macaque)	8	4	Projectile	Throw stones, unclear connection.	0	unclear	Stone			Bernstein pers. com. 1973 in Beck 1980
Macaca nemestrina (Southern Pig-tailed macaque)	8	4	Projectile	Tied up stick is thrown at competing animals. Learned after accidentally dropping the stick and realizing the capability of throwing a tied up stick.	0	Subsistence	Staff			Beck 1980; Geberer pers. com. 1977 in Beck 1980
Macaca nigra (Celebes crested macaque)	8	4	Toy	Branch and pieces of wood carried around, stuck into fence and sat on.	99	Game	Branch	Piece of wood		Bernstein pers. com. 1973 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Macaca nigra (Celebes crested macaque)	8	1	Projectile	Throw stones over cliff in a display of strength and to impress - agonistic display.	0	Impress, Threat?	Stone			Nickelson & Lockard 1978 in Beck 1980
Macaca silenus (Lion-tailed macaque)	8	5	Probe	Extract honey from container with a stick.	0	Subsistence	Staff			Westergaard 1988 in Ueno & Fujita 1998
Macaca speciosa (Stump-tailed macaque)	8	4	Projectile	Throw sand and stones at zoo visitors. Learned from rude children.	0	Impress, Threat	Sand	Stone		Heck in Armbruster 1921 in Beck 1980
Macaca sylvana (Barbary macaque)	8	1	Hammer	Kill scorpion with stone.	0	Defense?	Stone			Turckheim in Hladik 1973 in Beck 1980
Macaca sylvana (Barbary macaque)	8	1	Social Stimulus	Use young animals as buffer when approaching other young males. In captivity: dead young animals also used. Agonistic buffering.	0	Protection	Young animal			Deag & Crook 1971, Whiten & Rumsey 1973, Merz 1978 in Beck 1980
Macaca sylvana (Barbary macaque)	8	1	Projectile	Throw roof shingles at pursuers.	1	Threat, Defense	Roof shingle			Boulenger 1936 in Beck 1980
Macaca tonkeana (Tonkean macaque)	8	5	Probe	Extract honey from container with stick.	0	Subsistence	Staff			Anderson 1985 in Ueno & Fujita 1998
Macaca tonkeana (Tonkean macaque)	8	5	Fishing rod	Prepared sticks used to reach box of food placed out of reach. Stick with sufficient length is chosen from the prepared sticks.	0	Subsistence	Stick			Ueno & Fujita 1998
Mandrillus leucophaeus (Drill)	8	4	Stimulation?	Rub fresh branches and oranges on its chin, mouth and chest.	0	Stimulation?	Branch	Orange peels		Fiedler 1957 in Beck 1980
Mandrillus leucophaeus (Drill)	8	4	Projectile	Stones and other objects aimed at humans.	99	Threat, Defense?	Stones	other objects		Armbruster 1921, Schultz 1961, Anonym in Kortlandt & Kooij 1963 in Beck 1980
Mandrillus sphinx (Mandrill)	8	4	Projectile	Throw sand around at nearby humans, agonistic.	0	Threat, Defense?	Sand			Beck 1975 in Beck 1980
Mandrillus sphinx (Mandrill)	8	4	Projectile	Aimed throwing.	99	Threat, Defense?	?			Anonym in Kortlandt & Kooij 1963 in Beck 1980
Mandrillus sphinx (Mandrill)	8	4	Probe	Probe into infected ear with a small stick or stem. Selected for the best length, thickness and stiffness. Single observation over 40 min. Tools in part broken off.	1	Personal hygiene	Small stick	Stem		Vincent 1973 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Nasalis larvatus (Proboscis monkey)	8	1	Projectile	Throw branches at human observers.	1?	Threat, Defense?	Branch			MacKinnon 1971 in Beck 1980
Papio anubis (Olive baboon)	8	1	Projectile	Throw stones at partially know humans. Offensive action.	0	Threat, Defense?	Stein			Pettet 1975, Pickford 1975 in Beck 1980; Pettet 1975, Pickford 1975 in Becker 1993
Papio anubis (Olive baboon)	8	4	Instrument used for hitting	Try to hit observer with a metal plate.	0	Threat	Stone			Maple 1975 in Beck 1980
Papio anubis (Olive baboon)	8	4	Fishing rod	Fish for food with a stick or staff.	99	Subsistence	Stick	Staff		Benhar & Samuel 1978, Choudhury pers. com. 1978 in Beck 1980
Papio Anubis (Olive baboon)	8	1	Social stimulus	Use young animal as buffer when approaching other males. Agonistic buffering	0	Protection	Young animal			Ransom & Ransom 1971 in Beck 1980
Papio anubis (Olive baboon)	8	1	Social stimulus	Approach female with a young animal for grooming/lousing.	0	Social contact	Young animal			Ransom & Ransom 1971 in Beck 1980
Papio anubis (Olive baboon)	8	1	Projectile	Drop stones on partially known humans. Offensive action.	0	Threat, Defense?	Stone			Pettet 1975, Pickford 1975 in Beck 1980; Pettet 1975, Pickford 1975 in Becker 1993
Papio anubis (Olive baboon)	8	1	Probe	Use stick to scatter and sort stones, to sort mud for stones, to probe for stones in mud and fish them out. Then swallow chosen stones. Single observation in an adult male.	99	Personal hygiene	Stick			Oyen 1978 in Beck 1980; Oyen 1978 in Becker 1993
Papio anubis (Olive baboon)	8	1	Projectile	Throw stones at goats to kill and eat them (reported by natives).	0	Subsistence	Stone			Pickford 1975 in Becker 1993
Papio anubis (Olive baboon)	8	1	Instrument for cleaning	Use pebbles to wipe mouth after eating a sticky fruit. Another male used a corncob to wipe blood and spit from its mouth after a fight.	0	Personal hygiene	Stone	Ear of corn		van Lawick-Goodall et al. 1973; van Lawick-Goodall et al. 1973 in Beck 1980; Goodall et al. 1973 in Becker 1993
Papio cynocephalus (Yellow baboon, Babuin)	8	1	Probe	Use thin twig or stem to poke into underground termite nest, pull out and eat the termites - termite fishing.	1	Subsistence	Twig	Stem		Broda pers. com. 1975 in Beck 1980; Broda pers. com. 1975 in Beck 1980 in Becker 1993
Papio cynocephalus (Yellow baboon, Babuin)	8	4	Fishing rod	Fish for food using a stick or staff.	99	Subsistence	Stick	Staff		Nellman & Trendelenburg 1926 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Papio cynocephalus anubis (Yellow baboon, Babuin)	8	5	Sponge	Use soft material as a sponge to soak up liquids.	0	Subsistence	Soft material			Westergaard 1992 in Ueno & Fujita 1998
Papio hamadryas (Hamadryas baboon)	8	1	Projectile	Throw sand and dust into the eyes of non-human predators.	0	Threat, Defense?	Sand	Dust		Ludolph in Lydekker 1910 in Beck 1980
Papio hamadryas (Hamadryas baboon)	8	4	Lever	Use metal staff as lever between the wall and door of their cage.	0	Locomotion	Metal rod			Beck 1980
Papio hamadryas (Hamadryas baboon)	8	4	Fishing rod	Aimed throwing of sticks behind food to pull it closer.	99	Subsistence	Staff			Beck 1972, 1973b in Beck 1980
Papio hamadryas (Hamadryas baboon)	8	1	Projectile	Roll stones, in part in a fight against Theropithecus gelada.	0	Threat, Defense?	Stone			Forbes in Zuckerman 1932, Forbes in Hall 1963 in Beck 1980
Papio hamadryas (Hamadryas baboon)	8	4	Fishing rod	Fish for food with a stick or staff.	99	Subsistence	Stick	Staff		Beck 1972, 1973b, Kats 1972b in Beck 1980
Papio hamadryas (Hamadryas baboon)	8	5	Fishing rod	Small female monkey retrieves stick from a hard to reach cage and gives it to larger monkey who uses it to fish for food. They share the food.	99	Subsistence	Stick			Beck 1973b in Beck 1980
Papio hamadryas (Hamadryas baboon)	8	4	Toy	Dug up 500g stone and carried it around, manipulated it for over an hour. Throw stone onto platform after the platform could not be reached while carrying the stone.	1	Game	Stone			Beck 1980
Papio hamadryas (Hamadryas baboon)	8	1	Social stimulus	Use young animal as buffer when approaching other males. Agonistic buffering	0	Protection	Young animal			Kummer 1967 in Beck 1980
Papio hamadryas (Hamadryas baboon)	8	4	Toy	Stick used as toy among young baboons.	99	Game	Stick			Beck 1973b in Beck 1980
Papio papio (Guinea baboon, Savanna baboon)	8	4	Fishing rod	Fish for food using stick or staff.	99	Subsistence	Stick	Staff		Beck 1973a, Guillaume & Meyerson 1934 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Papio papio (Guinea baboon, Savanna baboon)	8	4	Fishing rod	Aimed throwing of sticks behind food to pull it closer.	99	Subsistence	Staff			Beck 1973a in Beck 1980
Papio papio (Guinea baboon, Savanna baboon)	8	1	Social stimulus	Approach female with young animal.	0	Social contact	Young animal			Boese pers. com. 1976 in Beck 1980
Papio papio (Guinea baboon, Savanna baboon)	8	1	Social stimulus	Use young animal as buffer when approaching other males. Agonistic buffering	0	Protection	Young animal			Boese pers. com. 1976, Hamilton et al. 1978 in Beck 1980
Papio papio (Guinea baboon, Savanna baboon)	8	4	Fishing rod	Food outside of cage. Tail of young animal that fits through the bars is held. As soon as it has filled its cheeks with the food it is pulled back and the food is taken away.	0	Subsistence	Young animal			Garvey pers. com. 1977 in Beck 1980
Papio sp. (Baboon)	8	1	Pestle	Stick used to poke into termite nest.	99	Subsistence	Stick			Kortlandt + Kooij 1963, van Lawick-Goodall et al. 1973
Papio sp. (Baboon)	8	1	Digging stick	Use stick to broaden the entrance to underground insect nests.	99	Subsistence	Stick			Jobaert in Kortlandt & Kooij 1963 in Beck 1980
Papio sp. (Baboon)	8	1	Pestle	Use stone to squash scorpion before eating it.	0	Subsistence	Stone			Kortlandt + Kooij 1963, van Lawick-Goodall et al. 1973
Papio sp. (Baboon)	8	1	Hammer	Immobilize scorpion with rock before eating.	0	Subsistence	Stone			Davison in Kortlandt & Kooij 1963, Vachon in Hladik 1973, Watson in Oakley 1961 in Beck 1980
Papio ssp. (Baboon)	8	1	Projectile	Aim dust, sand, gravel and plants at humans, sand and gravel at crocodile. Baboons in captivity throw stones, sand, gravel, bananas and other objects in agonistic contexts.	0	Threat, Defense?	Sand	Gravel	other objects	Anonym in Kortlandt & Kooij 1963, Hamilton et al. 1978, Owen in Kortlandt & Kooij 1963, Armbruster 1921, Bolwig 1961, 1964, Hornaday 1934 in Beck 1980
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Fishing rod	Use stick to reach objects that are out of reach.	99	unclear	Stick			Bolwig 1961, van Lawick-Goodall et al. 1973
Papio ursinus (Chacma baboon, Cape baboon)	8	1	Cushion	Carry fallen palm frond to tree stump and sit on it.	0	Personal hygiene	Palm frond			Hamilton et al. 1978 in Beck 1980; Hamilton et al. 1978 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Fishing rod	Fish for food with a stick and staff. In part, a stick was used to fish for a longer stick, sticks that were not clearly associated with the food.	99	Subsistence	Stick	Staff		Bolwig 1961,1964 in Beck 1980
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Projectile	?	99	unclear	?			Bolwig 1961, Kortlandt + Kooij 1963, van Lawick-Goodall et al. 1973
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Digging stick	Dig with stick. Unclear connection.	99	unclear	Stick			Bolwig 1964 in Beck 1980
Papio ursinus (Chacma baboon, Cape baboon)	8	1	Projectile	Throw mud and stones at humans.	0	Threat, Defense?	Mud	Stone	Palm nut	Smith in Romanes 1892 in Beck 1980; Hornaday 1923, Romanes 1904,Hamilton et al. 1975 in Becker 1993
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Fishing rod	Aim and throw staffs behind food in order to pull it closer. Also threw stick behind banana to get at it.	99	Subsistence	Staff	Stick		Bolwig 1961, 1964 in Beck 1980
Papio ursinus (Chacma baboon, Cape baboon)	8	1	Projectile	Roll, drop and throw rocks at pursuers. Stones on average 583g, 165 x 104mm (n = 124). Predominantly by juvenile and adult males at partially known humans. Previously dug up by hand.	1	Threat, Defense?	Stone			Shipp in Romanes 1892, Rawlinson in Hornaday 1934, Lydekker 1910, Hamilton et al. 1975 in Beck 1980; Hornaday 1923, Romanes 1904, Hamilton et al. 1975 in Becker 1993
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Lever	Use stick as lever for digging. Unclear connection.	99	unclear	Stick			Bolwig 1964 in Beck 1980
Papio ursinus (Chacma baboon, Cape baboon)	8	1	Hammer	Use stone to open hard-shelled fruits of the monkey-bread tree. Up to four fruits were plucked and carried over a larger distance to a rock where they were then broken open.	0	Subsistence	Stone			Marais 1969, van Lawick-Goodall et al. 1973 in Beck 1980; Marais 1973 in Becker 1993
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Ladder	Balance stick or stick it into the ground and climb up it to reach food that is located out of reach, or for play.	99	Subsistence, Game	Stick			Bolwig 1961, 1964 in Beck 1980
Papio ursinus (Chacma baboon, Cape baboon)	8	4	Probe	Stick blade of grass into a pipe and then lick off the oil sticking to it.	1?	Subsistence	Blade of grass			Marais 1969 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pithecia ssp. (Saki monkeys)	8	1	Projectile	Throw branches at pursuers.	1?	Threat, Defense?	Branch			Anonym in Koortlandt & Kooij 1963 in Beck 1980
Presbytis (Trachypithecus) cristatus (Silvery lutung)	8	1	Projectile	Break off and then throw dead branches at human observers.	1	Threat, Defense?	Branch			Lydekker 1910 in Beck 1980
Presbytis (Semnopithecus) entellus (Northern Plains gray langur)	8	1	Projectile	Throw rocks at human observers.	0	Threat, Defense?	Stone			Jennison 1927 in Beck 1980
Saimiri sciureus (Common Squirrel monkey)	8	1	Club	Swipe fruit across the ground with a stick to remove ants.	99	Subsistence	Stick			Chippendale in Kortlandt and Kooij 1963 in Beck 1980
Saimiri spp. (Squirrel monkeys)	8	1	Projectile	Throw branches at pursuers.	1?	Threat, Defense?	Branch			Anonym in Koortlandt & Kooij 1963 in Beck 1980
Theropithecus gelada (Dschelada, Gelada baboon)	8	1	Projectile	Roll stone, in part in a fight against Papio hamadryas.	0	Threat, Defense?	Stone			Forbes in Zuckerman 1932, Forbes in Hall 1963 in Beck 1980
Gorilla beringei? (Eastern Gorilla)	9	1	Projectile	Drop or throw branches at pursuers. Once, branch was intentionally broken off.	1	Threat, Defense?	Branch			Merfield & Miller 1956, Baumgartel in Kortlandt & Kooij 1963 in Beck 1980
Gorilla beringei? (Eastern Gorilla)	9	1	Projectile	Aim and throw tires, sand, straw, water, dung, vegetables, sticks at other monkeys and humans. In captivity and the wild.	99	Threat, Defense?	Sand	Dung	other objects	Beck 1980; Fossey in Chevalier-Skolnikoff 1977, Groves 1970, Smith in Kortlandt & Kooij 1963 in Beck 1980; Fossey 1970, 1991; Merfield 1961 in Becker 1993
Gorilla beringei? (Eastern Gorilla)	9	1	Tickle stick	Old male gorilla plucked long-stemmed flower to tickle younger animal (single observation).	1	Social contact	Flower			Fossey 1970, 1991 in Becker 1993
Gorilla gorilla (Gorilla)	9	4	Probe	Frequent probing in the San Francisco zoo. Dip straw in urine outside of the cage and brought it to lips.	99	Exploration	Straw	other objects		Chevalier-Skolnikoff 1977, Teleki in van Lawick-Goodall 1970 in Beck 1980
Gorilla gorilla (Gorilla)	9	4	Audio stimulus	Take water into hands before drumming on chest.	0	Impress, Threat?	Water			Thompson pers. com. 1976 in Beck 1980; Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Gorilla gorilla (Gorilla)	9	1	Cover	In the wild, gorillas drape lobelia leaves and moss onto their heads as part of a game. In captivity, they place straw, pieces of wood, dung and other objects on their back instead.	99	Game	Leaves	Moss	other objects	Schaller 1963, Carpenter 1937 in Beck 1980; Beck 1980
Gorilla gorilla (Gorilla)	9	1	Cushion	Place straw in a puddle to have a dry place to sit.	0	Personal hygiene	Straw			Yerkes 1928-29, Philipps 1950 in Beck 1980
Gorilla gorilla (Gorilla)	9	4	Container	Use boxes or other hollow containers to scoop up water for drinking.	0	Subsistence	Box	other objects		Carpenter 1937 in Beck 1980
Gorilla gorilla (Gorilla)	9	4	Frond	Drive off flies with twigs.	99	Personal hygiene	Twig			Zenker in Armbruster 1921, Zenker in Yerkes & Yerkes 1929 in Beck 1980
Gorilla gorilla (Gorilla)	9	5	Ladder	Balance a stick or climb a pole to reach food.	99	Subsistence	Stick	Pole		Yerkes 1927a, 1927b in Beck 1980
Gorilla gorilla (Gorilla)	9	1	Projectile	Throw branches, twigs, leaves, herbs around as part of threatening behavior against humans and other gorillas. In captivity: throw straw, sand, water. Branches, twigs and leaves are also torn off.	1	Threat, Defense?	Branch	Twig	other objects	Emlen 1962, Groves 1970, Geddes/Merfield/Rahm/Rollais in Kortlandt & Kooij 1963, Schaller 1963 in Beck 1980; Beck 1980
Gorilla gorilla (Gorilla)	9	1	Club	Wild: Hit humans with torn out bamboo plants. Captivity: Hit different unclear targets with unspecified objects in unclear contexts.	1	Threat, Defense	Bamboo	Objects		Kortlandt & Kooij 1963 in Beck 1980; Emlen 1962 in Becker 1993
Gorilla gorilla (Gorilla)	9	4	Projectile	Aimed throwing game.	99	Game	Objects			Kortlandt & Kooij 1963 in Beck 1980
Gorilla gorilla (Gorilla)	9	5	Fishing rod	Blanket thrown onto food that can't be reached with a stick to pull it closer and into reach.	0	Subsistence	Blanket			Natale et al. 1988
Gorilla gorilla (Gorilla)	9	1	Optical stimulus	Swing objects as part of threatening behavior.	1	Impress, Threat	Pole	Branch		Cordier in Groves 1970, Cordier in Kortlandt & Kooij 1963, Joines 1976 in Beck 1980
Gorilla gorilla (Gorilla)	9	6	Ladder	Stack up to four crates to form a tower and reach food placed out of normal reach. Involves training.	3	Subsistence	Boxes			Yerkes 1927a, 1927b, 1928-29 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Gorilla gorilla (Gorilla)	9	4	Sponge	Dunk coconut fibers in water and squeeze it into mouth. Training: Dunk rope in water and then suck/lick the water.	0	Subsistence	Coconut fibers	Rope		Parker 1968a, 1969 in Beck 1980; Fontaine et al. 1995
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	1	Walking stick	Walking stick to cross a swamp, test the water depth, also serves as support.	1	Locomotion	Stick			Breuer et al. 2005
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	4	Club	Knock down leaves and fruits.	0	Subsistence	Stick			Nakamichi 1999
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	4	Projectile	Throw stick to knock down leaves and fruits that are out of reach, from the tree.	0	Subsistence	Stick			Nakamichi 1998, 1999
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	1	Bridge	Branch that was first used as a crutch/support is pulled out and then laid across the swamp and crossed on four feet.	1	Locomotion	Stick			Breuer et al. 2005
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	1	Crutch	Dead branch (1.3-5cm diameter) broken from bush, rammed into the swamp using both hands and used as a stabilizing pole to hold onto while fishing water plants near the bank of the swamp.	1	Stabilization, Subsistence	Stick			Breuer et al. 2005
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	1	Fishing rod	Use stick to reach objects that are out of reach.	1, 2, 4	Subsistence	Stick	Tree trunk		Chevalier-Skolnikoff 1977, Phillips 1950, Pitman in Schaller 1963, Parker 1968a, 1969, Redshaw 1975, Hughes & Redshaw 1974, Yerkes 1927a, 1927b, 1928-29 in Beck 1980; Philipps 1950, Pitman 1935, 1943 in Becker 1993; Nakamichi 1999; Fontaine et al. 1995
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	4	Projectile	Aimed throwing of sticks at other gorillas and humans. Other objects. In the wild?	0	Threat, Defense?	Stick	other objects?		Fontaine et al. 1995 (Beck 1980; Fossey in Chevalier-Skolnikoff 1977, Groves 1970, Smith in Kortlandt & Kooij 1963 in Beck 1980; Fossey 1970, 1991; Merfield 1961 in Becker 1993?)
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	4	Probe	Chew on end of thin twigs or sticks to make them sharp, use them to clean ear or navel of a younger animal (son).	4	Brood care	Twig	Stick		Fontaine et al. 1995

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	4	Ladder	Lean tree trunk against wall and climb it to reach the platform. Single attempt to pull the pole up to the platform and then continue to climb over fence.	0	Locomotion	Tree trunk			Fontaine et al. 1995
Gorilla gorilla gorilla (Western Lowland Gorilla)	9	4	Rag	Dip coconut fibers into water to clean back and backside of a young animal. Clean dung-covered hands of a young animal with dry fibers.	3	Brood care	Coconut fibers	Water		Fontaine et al. 1995
Hylobates lar (Lar gibbon, Lar)	9	4	Swinging rope	Fasten rope and pipes to bars of the cage, use it as a swinging rope.	3	Locomotion, Game?	Rope	Pipe		Rumbaugh 1970 in Beck 1980
Hylobates lar (Lar gibbon, Lar)	9	4	Sponge	Hold fabric in front of water dispenser until soaked with water. Suck water from the fabric or wait until it dripped into a puddle to drink it.	0	Subsistence	Fabric			Rumbaugh 1970 in Beck 1980
Hylobates lar (Lar gibbon, Lar)	9	4	Projectile	Aim and throw banana peals at cage mates as part of a game.	0	Game	Banana peel			Judge pers. com. 1973 in Beck 1980
Hylobates lar (Lar gibbon, Lar)	9	1	Projectile	Break off, drop or throw down dead branches at human observers. Branches broken off and thrown as part of threatening behavior within the species.	1	Threat, Defense?	Branch			Carpenter 1940, Ellefson in Baldwin& Teleki 1976 in Beck 1980; Carpenter 1940, Ellefson 1967 in Becker 1993
Hylobates sp. (Gibbon)	9	5	Fishing rod?	Use instrument to fish for food that is out of reach. Only when reward was placed between fishing rod and animal?	99	Subsistence	?			Boulenger 1936, Drescher & Tendelenburg 1927 in Beck 1980
Pan paniscus (Bonobo)	9	4	Probe	Smelling probe, inspect holes by sticking a probe inside and then smelling it- investigatory probe, reach, sniff.	99	Exploration	Branch	Straw	Stick	Jordan 1982
Pan paniscus (Bonobo)	9	1	Cover	Cover the stomach with twigs and leaves in the nest, especially during the rainy period.	1	Personal hygiene	Twig	Leaves		Fruth 1995 in Hohmannn & Fruth 2003

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan paniscus (Bonobo)	9	1	Optical and audio stimulus	Break off branch or crown of a tree, sometimes vines. Drag it behind when running, accompanied by shouts. When members of different groups meet: impressive, agonistic display.	1	Impress, Threat	Branch			Ingmanson 1996; Badrian & Badrian 1984, Ingmanson 1996 in Hohmannn & Fruth 2003
Pan paniscus (Bonobo)	9	4	Hook	Hook used to reach for and pull close branches or other objects that are out of reach.	99	unclear	Stick			Jordan 1982
Pan paniscus (Bonobo)	9	1	Optical stimulus	Leaf-clip by hand: Pluck plant materials as during the search for food. Not eaten. Only adult females in an attempt to attract males.	1	Attention	Leaf			Hohmann & Fruth 2003
Pan paniscus (Bonobo)	9	1	Frond	Swipe away flying insects from genital swellings or wounds with a leafy branch.	1?	Personal hygiene	Twig			Ingmanson 1996; Hohmannn & Fruth 2003
Pan paniscus (Bonobo)	9	1	Toy	Play with objects as an indicator: Stick as symbol for who is "it" to be caught. Game with stick lasts longer and occurs more frequently than without?	1?	Game	Stick			Ingmanson 1996
Pan paniscus (Bonobo)	9	4	Mop	Long leafy branch to sweep away suds from the cage.	99	Nest building	Branch			Jordan 1982
Pan paniscus (Bonobo)	9	1	Toy	Play with stick, leafy branch, blossoms, and fruit. Individual game.	1?	Game	Branch	Blossom	other objects	Ingmanson 1996
Pan paniscus (Bonobo)	9	1	Projectile	Drop or throw down branches etc. Repeated with same object after it is retrieved.	99	Impress, Threat	Branch	other objects		Ingmanson 1996
Pan paniscus (Bonobo)	9	1	Projectile	Aim and throw branches and sticks at humans and other bonobos (juveniles and adults, both sexes). In captivity: aim and throw branch, dung or bucket (at a female).	99	Impress, Threat	Bucket	Stick	other objects	Jordan 1982; Hohmann & Fruth 2003; Savage 1976 in Beck 1980
Pan paniscus (Bonobo)	9	4	Container	Bucket to catch urine.	0	Personal hygiene	Bucket			Savage 1976 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan paniscus (Bonobo)	9	4	Projectile	Throw stick, piece of wood, plastic container.	99	Threat, Game	Stick	Piece of wood		Jordan 1982; Savage 1976 in Beck 1980
Pan paniscus (Bonobo)	9	1	Optical and audio stimulus	Break off branch or crown of a tree, sometimes vines. Drag it behind when running, accompanied by shouts. When members of different groups meet: impressing, agonistic display.	1	Attention	Branch			Ingmanson 1996; Badrian & Badrian 1984, Ingmanson 1996 in Hohmannn & Fruth 2003
Pan paniscus (Bonobo)	9	1	Toy	Catch guenon (Cercopithecus ascanius), colobus monkey (Colobus angolensis), to play with. Apenheul Primate Park: Catch frogs and chicks, carry them around, and drop them when they died.	0	Game	Monkey			Sabater Pi et al. 1993 in Hohmann & Fruth 2003; Gold 2002
Pan paniscus (Bonobo)	9	1	Seat	Bend down small trees and bushes to sit on the leafy parts.	4	Personal hygiene	Twig	Tree	Bush	Hohmannn & Fruth 2003
Pan paniscus (Bonobo)	9	4	Lever	Use a stick as a lever to break open wire fence.	99	unclear	Stick			Jordan 1982
Pan paniscus (Bonobo)	9	1	Rag	Use leaves to clean body from other animal's fecal matter. In captivity: use wood wool to wipe away fecal matter and water from their own body.	99	Personal hygiene	Leaves	Wood wool		Jordan 1982; Ingmanson 1996; Ingmanson 1996 in Hohmann & Fruth 2003
Pan paniscus (Bonobo)	9	1	Toy	Leaf-clip by mouth: juveniles of both sexes and adult females pluck small leaves and hold them with their lips while watching other individuals. Form of social play?	1	Game	Leaf			Hohmann & Fruth 2003
Pan paniscus (Bonobo)	9	1	Probe	Toothpick made out of a small twig. Used teeth to produce (two times by the same individual).	1?, 2	Personal hygiene	Twig			Ingmanson 1996; Ingmanson 1996 in Hohmann & Fruth 2003
Pan paniscus (Bonobo)	9	4	Audio stimulus	Make sounds by knocking branches against the bars of the cage.	99	Impress?, Attention?	Branch			Jordan 1982

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan paniscus (Bonobo)	9	1	Scraper	Scratch back with a twig it broke off or a stick (picked up from the ground and transported to a tree to scratch itself) (Two individual observations).	1	Personal hygiene	Twig	Stick		Ingmanson 1996; Hohmann & Fruth 2003
Pan paniscus (Bonobo)	9	1	Sponge	Wild: Soak up water from trees with moss. In captivity: Use leaves (brought from a few meters away), wood wool, and tennis ball, to soak up water from the ground or from a basin. Suck water out of object multiple times.	99	Subsistence	Moss	Leaves	other objects	Jordan 1982; Hohmannn & Fruth 2003
Pan paniscus (Bonobo)	9	4	Container	Use bell pepper halves to scoop water and drink it.	0	Subsistence	Bell pepper halves			Jordan 1982
Pan paniscus (Bonobo)	9	4	Container	Plastic container halves used to collect and transport water.	0	Transport, Subsistence	Plastic container			Jordan 1982
Pan paniscus (Bonobo)	9	4	Audio stimulus	Make sounds by kicking a plastic container.	0	Impress?, Attention?	Plastic container			Jordan 1982
Pan paniscus (Bonobo)	9	4	Swinging rope	Use long branches, wrapped around a bar. Tie and braid the ends together and used as a swing for swinging.	3, 4	Game	Twig			Jordan 1982
Pan paniscus (Bonobo)	9	1	Digging stick	Sticks covered with mud near termite nests. Used to dig up termites or mushrooms?	99	Subsistence?	Stick			Kano 1979 in Becker 1993
Pan paniscus (Bonobo)	9	1	Audio stimulus	Strip leaves from branches or small trees. Juveniles and adults of both sexes. In part when meeting members of another group.	1	Impress, Threat?	Leaves			Hohmann & Fruth 2003
Pan paniscus (Bonobo)	9	4	Audio stimulus	Make sounds by hitting a metal drum, chain.	0	Impress?, Attention?	Metal drum	Chain		Jordan 1982
Pan paniscus (Bonobo)	9	4	Ladder	Branch leaned against a tree trunk used as ladder multiple times. To climb over a smooth cylinder or electronic fence. Multiple observations in a female animal.	0	Locomotion	Stick			Gold 2002

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan paniscus (Bonobo)	9	1	Cover	Leafy branch used as protection from rain by placing it overhead, neck and shoulders. Passed on only (?) from mother to child.	1	Personal hygiene	Branch			Kano 1982; Ingmanson 1996; Kano 1982 in Becker 1993; Hohmannn & Fruth 2003
Pan paniscus (Bonobo)	9	6	Blade	Flake used to cut string that tied up a box with a reward in it. Principle/ Use / Flake production shown. Knapped using the hard blow technique. Shatter the core by throwing it on the ground.	2	Subsistence	Stone			Toth et al. 1993
Pan paniscus (Bonobo)	9	4	Club	Use a stick to club a hen defending her young (8 min). Did not eat the dead animal. Observed once in a female animal.	0	unclear (stress/ aggression reduction?)	Stick			Gold 2002
Pan paniscus (Bonobo)	9	1	Audio stimulus	Cover an antelope with twigs without hurting it - game.	1?	Game	Twig			Kano 1979 in Becker 1993
Pan paniscus (Bonobo)	9	1	Audio stimulus	Strip leaves from branches or young trees. Juvenile and adults of both sexes.	1	Game	Leaves			Hohmannn & Fruth 2003
Pan paniscus (Bonobo)	8	4	Ball	Kick a tennis ball.	0	Game	Tennis ball			Jordan 1982
Pan paniscus (Bonobo)	9	4	Frond	Stick, branch, rope, chain, and wood wool: swung around as part of threatening behavior.	99	Impress, Threat	Stick	Branch	other objects	Jordan 1982
Pan paniscus (Bonobo)	9	4	Frond	Stick, branch, rope, chain, and wood wool: swung around as part of game.	99	Game	Stick	Branch	other objects	Jordan 1982
Pan paniscus (Bonobo)	9	4	Club	Branch or stick used in threatening behavior.	99	Impress, Threat	Branch	Stick		Jordan 1982
Pan paniscus (Bonobo)	9	4	Club	Branch, stick or club used in a game. Apenheul Zoo: club hen defending her chicks, to death.	99	Game	Branch	Stick		Jordan 1982
Pan troglodytes (Chimpanzee)	9	1	Pestle	Small twig, stick pounded multiple times into a termite hole, pull out squashed insects to eat them. 5-15cm long, side branches and leaves removed. 2 adult males, each for 30 min, not very successful.	1, 2	Subsistence	Twig			Whiten et al. 1999, 2001; Sugiyama & Koman 1979

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Pestle	Pound small stick into hole in tree and stir until resin sticks to it. Longer than the insect pestle: twig 10-20cm, side twigs and leaves removed with teeth. Extraction for up to 15 min. Juveniles and adults.	1, 2	Subsistence	Stick			Whiten et al. 1999, 2001; Sugiyama & Koman 1979
Pan troglodytes (Chimpanzee)	9	1	Digging stick	Stick used to perforate insect nests, tree stump for probe, Rio Muni: length 19.5-86.7cm, thickness 0.5-1.5cm, usually straight, both ends used, distances closer than 5m (1-24m). Stick broken / bitten off, defoliated, partially decorticated.	1, 2	Subsistence	Branch			Jones & Sabater Pi 1969; Sabater Pi 1974; Whiten et al. 1999, 2001; Sabater Pi 1972, Struhsacker & Hunkeler 1971 in Beck 1980; Nishimura et al. 2003; Stanford et al. 2000
Pan troglodytes (Chimpanzee)	9	1	Digging stick	Stick used as spade to dig termite nest: Campo: Stick: usually straight, 1-2 ends used, length 30.5 to 73.5 cm, thickness 4-15mm, raw material from the immediate vicinity, digging stick - point removed, defoliated.	1, 2	Subsistence	Branch			Sugiyama 1985, Whiten et al. 1999; Jones & Sabater Pi 1969 in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Hook	Branch used to hook other branches.	1	Locomotion, Subsistence?	Branch			Whiten et al. 1999, 2001; Sugiyama & Koman 1979; Sugiyama & Koman 1979 in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Sponge	Moss collected and rolled together (few cm) to scoop water from holes in trees.	1, 4	Subsistence	Leaf			Lanjouw 2002
Pan troglodytes (Chimpanzee)	9	1	Container	Leaves held in hand, used to catch feces - container.	1?	Exploration, Personal Hygiene	Leaf			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Frond	Leaf used to brush away bees - leaf-brush.	1?	Subsistence	Leaf			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Rag	Leaves used to mop up insects - leaf-mop. Leaves plucked and crumpled.	1, 4	Subsistence	Leaf			Nishida 1973; Whiten et al. 1999, 2001; Beck 1980; Nishida 1973 in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Rag	Leaves used to wipe food from skull and fruits.	1?, 4	Subsistence	Leaf			Teleki 1974; Whiten et al. 1999, 2001; Teleki 1973a, 1973b, Wrangham 1977 in Beck 1980; Teleki 1974, Wrangham 1977 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Hammer	Stone or stick used to crack open nuts, used in combination with anvil, roots or ground. Weight of stone 1 to >5kg (depending on nut type, max. 16kg.), transported up to 100m. Rare in captivity.	1, 2	Subsistence	Stone	Stick		Sugiyama & Koman 1979; Boesch & Boesch 1981, 1983, 1984a, 1984b; Whiten et al. 1999, 2001; Beatty 1951, Rahm 1971, Struhsacker & Hunkeler 1971, Brewer 1976, Azuma & Toyoshima in Itani & Suzuki 1967 in Beck 1980; Anderson et al. 1983 in Becker 1993
Pan troglodytes (Chimpanzee)	9	4	Probe	Extraction stick or stem used to extract liquids such as water.	99	Game	Stick	Twig	Straw	Hobhouse 1926, Köhler 1927, Kollar 1972, Schiller 1957, van Lawick-Goodall 1970 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Fishing rod	Stem used to scoop algae from the water surface. Similar behavior in captivity: fish objects from the water ditch. Broken off? Defoliated.	1?, 2	Subsistence	Stem			Whiten et al. 1999, 2001; van Hooff 1973, Kollar 1972 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Wedge	Small stone used to adjust and level out the anvil.	0	Tool production, Subsistence	Stone			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Pestle	Use palm leaf stem to pound palm petiole until soft, to allow access to the palm hearts. Two handed use of the pestle similar to grinding grains.	1	Subsistence	Palm leaf stem			Yamakoshi & Sugiyama 1995; Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	4	Scraper	Scratch or self-groom with a stick or straw. Detached and tapered.	1, 4	Personal hygiene	Stick	Straw		King et al. 1978, Köhler 1927 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Pestle	Poke into and lever into cracks - playful exploration.	99	Game, Exploration	Stick			Schiller 1957 in Beck 1980
Pan troglodytes (Chimpanzee)	8	1	Scoop	Use a leaf-spoon to scoop water from holes in trees.	1	Subsistence	Leaf			Matsusaka et al. 2005; Whiten et al. 1999
Pan troglodytes (Chimpanzee)	9	4	Container	Scoop water from ditch while playing.	0	Game	Objects			van Hooff 1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Bait	Bait chickens with bread, then poke them afterwards.	99	Game	Bread			Köhler 1927 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Projectile	Drop or throw down branches, twigs, and tendrils onto pursuers, onto leopard (leopard model) Rare in captivity (stone). Break off branches twigs and leaves.	1	Threat, Defense	Branch	Plant tendril	other objects	Izawa & Itani 1966, Nishida 1968, 1970, Owen /Reynolds in Kortlandt & Kooij 1963, Sabater Pi 1972, 1974, Sugiyama 1969, Albrecht & Dunnett 1971, Köhler 1927 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Probe	Probe used to inspect unknown, interesting or scary objects (holes, new siblings, reptile, sticky banana etc) by poking it, sticking into it and then sniffing the probe (stick, twig, blade of grass, tendril?).	1?	Exploration	Twig	Stick	other objects	Whiten et al. 1999, 2001; van Lawick-Goodall 1968, 1970, 1971, 1973, Köhler 1927, Mottershead 1963, Menzel 1971, H. van Lawick in van Lawick-Goodall 1970; Albrecht & Dunnett 1971, Brewer & Brewer in van Lawick-Goodall 1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Comb	Use leaf stem to comb through hair.	1?	Personal hygiene	Leaf			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Toy	Object used to initiate and trigger game, branch broken off or other objects.	1	Game	Twig	Palm		Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	4	Rag	Wipe cage with paper, burlap sack, straw and leaves (imitate caretaker?).	99	unclear, Game?	Paper	Straw	other objects	Bernstein 1962, King et al. 1978, Kollar 1972 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Optical and audio stimulus	Drag large branch while running, demonstrate aggressiveness, intimidation. Also, drag small trees, rarely younger individuals. Also when irritated or during a thunderstorm.	1	Impress, Threat	Branch	Small tree	Young animal	Nishida & Hiraiwa 1982, Whiten et al. 1999, 2001; van Lawick-Goodall 1971, van Hooff 1973, Teleki 1973c in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Sponge	Use un-chewed, partially crumpled leaves/ vegetation to scoop water and squeeze it into mouth, leaf sponge. In captivity: also use straw or bread, in experiments place rope into banana mash. 20-30 times, > 10 min. long. 8 times as much water as when using fingers.	1, 4	Subsistence	Leaf	Bread	other objects	Whiten et al. 1999, 2001; Goodall 1964, McGrew 1977, van Lawick-Goodall 1965, 1968, 1970, 1971, 1973, Brewer & Brewer in van Lawick-Goodall 1970, Cowper 1971, Hobhouse 1926, Köhler 1927, Parker 1968a, 1969 in Beck 1980; Sugiyama & Koman 1979 in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Frond	Branch with leaves used to shoo away flying insects - fly whist, branch broken off.	1	Personal hygiene	Branch			Whiten et al. 1999, 2001; Sugiyama 1969 in Beck 1980; Sugiyama 1969, 1981 in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Probe	Small stick used to clear nose.	99	Personal hygiene	Branch			Whiten et al. 1999, 2001

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Club	Stick used to hit other chimpanzees, baboons, and leopard model. In captivity: strike humans, reptiles, mammals, and gorilla with stick, bucket or rags.	99	Threat, Defense	Stick	Bucket		Whiten et al. 1999, 2001; van Lawick-Goodall 1968, 1970, Itani & Suzuki 1967, Köhler 1927, Kollar 1972, Savage 1976, van Hooff 1973, Wilson & Wilson 1968, Kortlandt 1965, 1967a, Sheak 1924 in Beck 1980; van Zon & van Orshoven 1967, Albrecht in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Lever	Use stick as lever to reach ant nests in trees, to open underground bees' nests, open banana crates, widen holes in fence or open food dispenser.	99	Subsistence	Stick			Teleki 1974, Goodall 1964, van Lawick-Goodall 1968, 1970, 1971, 1973, Wrangham 1974, Brwer & Brewer pers. com. In van Lawick-Goodall 1973, Köhler 1927, Kollar 1972, Hobhouse 1926, McGrew et al. 1975 in Beck 1980;Goodall 1964 in Becker 1993
Pan troglodytes (Chimpanzee)	9	4	Spit	Spit insects using pointed straw.	4	unclear?	Straw			King et al. 1978 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Audio stimulus	Rip leaves off stem, as threat.	2	Impress, Threat?	Branch			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Sponge	Use chewed leaves to scoop up water, squeeze into mouth and soak up more water.	1, 4	Subsistence	Leaf			Whiten et al. 1999, 2001; Matsusaka et al. 2005
Pan troglodytes (Chimpanzee)	9	1	Extraction set	Set of two tools for termite hill. 1) twig used to open entrance previously closed by termites. 2) flexible probe with brush end used to fish for termites. Stem shortened, decorticated and chewed with teeth.	1, 2, 3, 4	Subsistence	Twig	Stem		Sanz et al. 2004
Pan troglodytes (Chimpanzee)	9	1	Frond	Wave branch like a flag to beg for food.	1	Attention, Subsistence	Branch			Nishida & Hiraiwa 1982
Pan troglodytes (Chimpanzee)	9	1	Audio stimulus	Hit stick onto tree trunk like a drum, make noise to beg for food.	99	Attention, Subsistence	Stick			Nishida & Hiraiwa 1982; Savage & Wyman 1843-1844, Robillard in Rahm 1971 in
Pan troglodytes (Chimpanzee)	9	1	Cover	Use leafy branches as an umbrella.	1	Personal hygiene	Branch			Nishida & Hiraiwa 1982; Izawa & Itani 1966 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Lever	Use stick, branch to open insect or bird nest entrances in a tree or in the ground. Also banana crates. In captivity: break open food dispensers, fence etc. Stick defoliated, prepared.	1, 2, 4	Subsistence	Stick	Branch		Whiten et al. 1999, 2001; Goodall 1964, van Lawick-Goodall 1968, 1970, Nishida 1973 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Audio stimulus	Tear off the leafy parts using hands and mouth, leave the risps of a leaf.	1	Attention	Leaf			Nishida & Hiraiwa 1982, Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Nest	Build nest (for sleeping) out of leafy branches (on the ground).	1?	Nest building	Branch			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Stimulation	Large stone or solid stick to tickle, satisfy itself - social activity without a social partner.	99	Stimulation	Stone	Stick		Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Probe	Fish for termites and tree-dwelling ants using blade of grass, twig or tendril, Mahale: max transport distance 100m. Object broken or bitten off, defoliated, shortened, decorticated, sharpened end.	1, 2, 4	Subsistence	Stem	Twig	Plant tendril	Nishida 1973; Nishida & Hiraiwa 1982; Whiten et al. 1999, 2001; Teleki 1974; Brewer 1976, Goodall1963a, 1963b, 1964, 1965, Hladik 1977, Jones & Sabater Pi 1969, McGrew et al. 1979, Sabater Pi 1974, Suzuki 1966, Teleki 1974, van Lawick-Goodall 1968, 1970 in Beck 1980; Suzuki 1966, Goodall 1963, 1986 in Becker 1993
Pan troglodytes (Chimpanzee)	9	5	Blade	Sharp bone splinter as by-product of previous experiments. Perforator used to perforate skin over bottle containing sweet drink.	0	Subsistence	Bone			Kitahara-Frisch et al. 1987
Pan troglodytes (Chimpanzee)	9	1	Cushion	Short smooth stick from kapok tree used as a seat-stick, no further preparation.	1	Subsistence?, Nest building?	Branch			Alp 1997, Whiten et al 1999, 2001
Pan troglodytes (Chimpanzee)	9	4	Ladder	Branches, posts, iron bars, ladders, boards leaned against the wall and used for climbing to reach food, hung out of reach.	99	Subsistence	Branch	Pole		Köhler 1927, Menzel 1972 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Poking stick	Poke while playing.	99	Game	unclear			Birch 1945 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Stimulation	Leaves used in self-satisfaction, intense grooming. Social activity without social partner.	99	Stimulation	Leaf			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Plate	Leaves used as plate to inspect ectoparasites, collect their own dung after eating meet and sort out the undigested pieces.	1?	Exploration, Personal hygiene, Subsistence	Leaf			Whiten et al. 1999, 2001; Halperin in McGrew 1979 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Probe	Use flexible piece of bark to fish for tree ants. Branch broken off, bark torn from branch.	1	Subsistence	Bark			Nishida 1973; Nishida & Hiraiwa 1982; Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Probe	Extraction stick or stem used to extract liquids such as water, honey. In captivity: extract liquid from tank with rubbish or special food dispenser (porridge). Detach and prepare.	1, 2, 4	Subsistence	Stick	Stem		Nishida & Hiraiwa 1982; Whiten et al. 1999, 2001; Savage & Wyman 1843-1844, Merfield & Miller 1956, Izawa & Itaki 1966, Goodall 1964, van Lawick-Goodall 1968, Albrecht & Dunnett 1971, Poulson 1974-1975, Köhler 1927, Boesch 1978 in Beck 1980; Savage & Wyman 1843-1844, Izawa & Itani 1966, Merfield 1961, Whitesides 1985 in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Probe	Use stick to test for bees, then disable bees to eat them.	99	Exploration, Subsistence	Stick			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Probe	Small extraction stick to pick bone marrow out of long bones and skull. Similar activities in captivity. Multiple occurances.	99	Subsistence	Stick			Whiten et al. 1999, 2001; Khroustov 1964, Khroustov in Tobias 1965, Yerkes 1943, Birch 1945, Hobhouse 1926 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Pestle	Heavy dead branch, to stir up insects and other animals by poking into holes. (Mahale: 118cm long, 400g).	1	Subsistence	Branch			Nishida 1973; Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Rag	Leaves used to clean self - blood, dung, urine, sperm, sticky food, mud, water, juice, and puss. A group from Tenerife cleaned blood from menstruation. In captivity: use straw, paper, twigs, and leaves.	1	Personal hygiene	Leaf	Paper	other objects	Nishida & Hiraiwa 1982; Whiten et al. 1999, 2001; Goodall 1964, van Lawick-Goodall 1965, 1968, 1970, 1971, 1973, Savage & Wyman 1843-1844, Merfield & Miller 1956, King et al. 1978, Köhler 1927, Bernstein 1962 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Extraction set	Set of two tools for termite hill. 1) twig used to open entrance previously closed by termites. 2) flexible probe with brush end used to fish for termites. Stem shortened, decorticated and chewed with teeth.	1, 2, 3, 4	Subsistence	Branch	Stem		Sanz et al. 2004
Pan troglodytes (Chimpanzee)	9	1	Plate	Squash ectoparasites on leaf.	1?	Personal hygiene	Leaf			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Cushion	Hold smooth short branch from Kapok tree between feet, use as stepping stick to avoid the thorns of the kapok tree.	1	Locomotion, Subsistence?	Branch			Alp 1997, Whiten et al. 1999, 2001

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Probe	Stick with 2 brush-ends (2-17cm), stiff, usually straight. Broken or bitten off, defoliated, without sediments. Production not clear. Possibly with stick (Sanz et al. 2004), part of extraction set. brush broken off, not functional.	1, 2	Subsistence	Branch			Sugiyama 1985; Whiten et al. 1999; Sugiyama 1985 in Becker 1993; Sanz et al. 2004; Takemoto et al. 2005
Pan troglodytes (Chimpanzee)	9	1	Extraction set	Set of four tools used to extract honey. 1. dead branch with sharp end (35-40cm, 2 cm thick) used as rough pestle, 2. fine pestle, broken off (25cm, 15mm), 3. Green branch (prepared to 30 cm, 1cm) used as pestle, 4. Probe, green tendril 75-80cm, 8mm.	1, 2, 3	Subsistence	Branch (dead)	Branch (green)	Plant tendril	Brewer & McGrew 1990
Pan troglodytes (Chimpanzee)	9	1	Sponge	Use folded leaves, not chewed, to scoop water out of holes in trees.	1, 4	Subsistence	Leaf			Tonooka 2001
Pan troglodytes (Chimpanzee)	9	1	Probe	Short stick used to collect ants, ant eaten one at a time.	1?	Subsistence	Branch			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Cushion	Seat cushion made out of large leaves to avoid wet surface.	1?	Personal hygiene	Leaf			Whiten et al. 1999, 2001; Hirata et al. 1998 in Hohmann & Fruth 2003
Pan troglodytes (Chimpanzee)	9	1	Probe	Termite and ant-fish using leaf midrib.	1, 2	Subsistence	Leaf			Nishida 1973, Nishida & Hiraiwa 1982, Whiten et al. 1999, 2001; Beck 1980 (Source: unclear)
Pan troglodytes (Chimpanzee)	9	1	Swab	Use leaves to examine wounds; leaf dabbed on wound and then examined.	1?	Exploration, Personal Hygiene	Leaf			Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	1	Optical stimulus	Swing sticks as part of game.	99	Game	Stick			van Lawick-Goodall 1970, Köhler 1927, Watty in Kortlandt & Kooij 1963 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Ladder	Branches and tree trunks leaned against the wall to climb up to the next platform and reach the crown of the tree and try to escape over the fence. Min. 3m long, 5cm thick, up to 15kg transported over 20m. From ground to platform, from platform on with same branch. Cooperation - one is holding the branch.	1	Locomotion	Branch			McGrew et al. 1975, Menzel 1972, 1973b in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	4	Ladder	Balance a stick or pole to climb up it as part of a game, 3-3.5m long poles.	99	Game	Stick	Pole		Menzel 1972, 1973b, Menzel et al. 1970 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Ladder	Balance a stick or pole to climb up it to reach food hung out of reach, 3-3.5m long poles.	99	Subsistence	Stick	Pole		Köhler 1927, Yerkes & Yerkes 1929 in Beck 1980
Pan troglodytes (Chimpanzee)	9	5	Fishing rod	Sticks, branches, twigs, rope, carpet, stem, straw, blanket, wire, cardboard used to reach food. Longer sticks pulled closer using smaller sticks (max 4 in a row, not lying directly in the vicinity of each other) Max. 3 additions, in part reshaped or relocated.	1, 3, 4	Subsistence	Stick	Stem	other objects	Köhler 1927, Hobhouse 1926, King et al. 1978, Kats 1972b, Schiller 1957, Jennison 1927, Jackson 1942, Jacobson et al. 1935, Menzel et al. 1970, Okano et al. 1973, Birch 1945, Bourne 1971, Döhl 1966, Guillaume & Meyerson 1930, 1934 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Ladder	Choose stick (not dead, 30-100cm long, right thickness) and stick it into fence. Stand on stick to climb over metal wall. Leaves, twigs and bark removed, stick shortened.	2	Locomotion	Stick			McGrew et al. 1975 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Tactal aid	Pieces of fabric placed around loose tooth, then used to pull tooth.	0	Personal hygiene	Fabric			McGrew & Tutin 1972,1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Probe	Use sticks and twigs to clean or remove loose teeth, by themselves or for other chimpanzees. Leaves torn off, other pieces removed.	2	Personal hygiene	Stick	Twig		McGrew & Tutin 1972,1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Probe	Ant-dipping: Collect ants (Dorylus nigricans). Dig ditch near nest, modify branch (average diameter 1cm, 66cm length, defoliated), strip ants from stick with its hand. Max. 75m tool transport directly to the nest.	1, 2	Subsistence	Branch			McGrew 1974, 1977, 1979, Goodall 1963a, 1964, 1965, van Lawick-Goodall 1968, 1970, 1973, Teleki 1974, Köhler 1927 in Beck 1980; Goodall 1963, 1986, Nishida 1973, McGrew 1974 in Becker 1993; Whiten et al. 1999, 2001
Pan troglodytes (Chimpanzee)	9	4	Poking stick	Poke other chimpanzees, humans, dogs, chickens, baboons with stick, wire, and whip.	99	Threat?	Stick	Wire	Whip	Köhler 1927, Kollar 1972, Sheak 1924, Birch 1945 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	2	Club	Wild animals hit at closed banana crate. Hit the cage fence or platform when food, placed out of reach, cant be reached.	99	Frustration reduction	Stick			Jackson 1942, Wrangham 1974 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Club	Hit the ground as part of game.	99	Game	Stick			Wilson & Wilson 1968 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Ladder	Stack boxes, metal drums, tires, chair, and table to reach an object hung out of reach. Up to four boxes transported, emptied first. Cooperation of max. 3 individuals. Usually in experimental situations.	2, 3	Locomotion, Subsistence	Boxes	Tire	other objects	Bingham 1929, Köhler 1927, Schiller 1957, Yerkes 1943, Yerkes & Learned 1925, Wazuro in Döhl 1966, Lorenz in McGrew et al. 1975, von ButtelReepen in Bierens de Haan 1931 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Club	Hit the ground with a stick when pursuing other chimpanzees, attacking leopard model and mungo.	99	Threat, Defense	Stick			Anonym in Kortlandt 195, Anonym in Kortlandt & Kooij 1963, Nishida 1970, Albrecht & Dunnett 1971, McGrew pers. com. 1976 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Projectile	Aim and throw stones, sticks, and clumps of dirt as part of game.	99	Game	Stone	Stick	Clumps of dirt	Cowper 1971, Köhler 1927, Wilson & Wilson 1968 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Projectile	Intentionally drop branches, leaves, previously broken and torn off as part of game.	1	Game	Branch	Leaves		Albrecht & Dunnett 1971, Goodall 1963a, 1964, van Lawick-Goodall 1968, 1970 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Projectile	Aim and throw a rock when hunting bush pigs, scattering the herd. Capture and eat young animal.	0	Subsistence, Hunting	Rock			Plooij 1978 in Beck 1980; Plooij 1978 in Becker 1993
Pan troglodytes (Chimpanzee)	9	1	Projectile	Aim and throw sticks, stones, banana peals, grass and plant matter during aggressive interactions with other chimpanzees (wild, only males, females rarely in captivity). In captivity: also throw sand and locks at other animals and humans.	99	Threat, Defense?	Stick	Stone	other objects	Nishida & Hiraiwa 1982; Whiten et al. 1999, 2001; Goodall 1964, van Lawick-Goodall 1970, 1971, Kortlandt 1965, 1967a, Cowper 1971, Kollar 1972, Mottershead 1963, Okano et al. 1973, van Hooff 1973, Wilson & Wilson 1968, Menzel 1971, 1972, 1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Projectile	Throwing objects around as part of game. Both sexes starting with 9 months.	0	Game	Objects			van Lawick-Goodall 1968 in Beck 1980; Goodall 1964, 1986 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Projectile	Throw objects around when it cant reach its desired goal (e.g. females when they are in the fertile phase of their cycle). Wild and in captivity.	0	Frustration reduction	Objects			Jackson 1942 in Beck 1980 (Source of frustration reduction among wild chimpanzees in Beck 1980 unclear)
Pan troglodytes (Chimpanzee)	9	1	Projectile	Throw branches, sticks, grass, leaves, sugar cane, fruits, palm nuts, containers, pots and other objects at other chimpanzees to threaten and impress, rain dance at leopard model - chimpanzee voices, bonobos, goat, mungo.	1	Threat, Defense?	Branch	Stone	other objects	Albrecht & Dunnett 1971, Goodall 1964, 1979, Kortlandt 1962, NcGrew pers. com. 1976, Nishida 1968, 1970, Reynolds & Reynolds 1965, Riss & Goodall 1977, van Lawick-Goodall 1965, 1968, 1970, 1971, 1973, Eaton 1978, Köhler 1927, Savage 1976 in Beck 1980;
Pan troglodytes (Chimpanzee)	9	4	Optical and audio stimulus	Pull stick around as part of game.	99	Game	Stick			van Lawick-Goodall 1970, 1971 in Beck 1980
Pan troglodytes (Chimpanzee)	9	2	Optical and audio stimulus	Wild: Roll and kick stones, furniture and containers. In captivity: wooden boxes, drums, and buckets.	0	Impress, Threat	Stone	Container	other objects	Albrecht & Dunnett 1971, Goodall 1963a, 1964, 1965, 1979, Nishida 1970, Riss & Goodall 1977, van Lawick-Goodall 1965, 1968, 1970, 1971, 1973, Köhler 1927, Savage 1976, Bernstein pers. com. 1973 in Beck 1980; Goodall 1973, 1986 in Becker 1993
Pan troglodytes (Chimpanzee)	9	4	Optical stimulus	Swing sticks in frustration when food is out of reach.	99	Frustration reduction	Stick			Schiller 1957 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Optical stimulus	Swing branches, small trees, sticks, palm fronds, sugar cane at humans, chimpanzees, bonobos, a leopard model, a mungo, and its own reflection. In captivity: at a hippopotamus. During a thunderstorm.	1	Impress, Threat	Branch	Stick	other objects	Albrecht & Dunnett 1971, Goodall 1963b, 1965, 1979, Kortlandt 1962, 1965, 1967a, McGrew pers. com. 1976, Morris & Goodall 1977, Nishida 1970, van Lawick-Goodall 1965, 1968, 1970, 1971, Köhler 1927, Kortlandt & Kooij 1963, van Hooff 1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Probe	Probe different things, holes and clefts with long objects such as sticks, twigs, and blades of grass, straw, nails. Wild and in captivity (e.g. locks).	99	Game, Exploration	Stick	Twig	other objects	van Lawick-Goodall 1968, 1970, 1973, Bingham 1929, Köhler 1927, Kollar 1972, Menzel et al. 1970, Schiller 1957, van Hooff 1973, Jennison 1927, McGrew et al. 1975 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Extraction set	Set of two tools for water: leaf sponge and twig to pull sponge out of tree hole.	1, 3, 4	Subsistence	Branch	Leaf		Sugiyama 1997

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pan troglodytes (Chimpanzee)	9	1	Club	Hit other chimpanzees with stick and bushel of grass as part of game. Also hit insects.	99	Game	Stick			Albrecht & Dunnett 1971, van Lawick-Goodall 1970, Köhler 1927 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Digging stick	Dig with sticks, pieces of wood, metal pole, wire.	99	Exploration	Stick	Metal rod	other objects	Köhler 1927, Kollar 1972, Menzel 1972, 1973b, Menzel et al.1970, van Hooff 1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Cover	Drape tendril, lichen, branch, leaves, straw, fruits, skins, blankets, fabric, cardboard, rope, chain, pipes over head, neck and back.	99	Game	Leaves	Paper	other objects	Izawa & Itani 1966, Reynolds & Reynolds 1965, Albrecht & Dunnett 1971, Bauer 1977, Bernstein 1962, Cowper 1971, Köhler 1927, Menzel et al. 1970, Merfield & Miller 1956, van Hooff 1973, Yerkes 1943, Yerkes & Learned 1925 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Container	Scoop water from ditch while playing.	0	Subsistence	Objects			van Hooff 1973 in Beck 1980
Pan troglodytes (Chimpanzee)	9	0	"toilet aid"	Stick or fruit as "toilet aid"	99	Personal hygiene	Stick	Fruit		Kortlandt &Kooij 1963 in Beck 1980
Pan troglodytes (Chimpanzee)	9	1	Hammer	Young animals in captivity hammer on the ground (or an insect) the wall, a stone with another stone.	0	Game	Stone			van Lawick-Goodall 1970, 1973, Menzel et al. 1970 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Digging stick	Dig up grass with a stone, root or stick. Only observed in captivity.	99	Subsistence	Stone	Stick		Sabater Pi 1974, McGrew et al. 1979, Cowper 1971, Köhler 1927 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Pestle	Poke into cracks when experimental tasks fail.	99	Frustration reduction	Stick			Jackson 1942, Menzel et al. 1970 in Beck 1980
Pan troglodytes (Chimpanzee)	9	4	Hammer	Hammer objects with sticks when experimental task failed.	99	Frustration reduction	Stick			Jackson 1942, Menzel et al. 1970 in Beck 1980
Pongo pygmaeus (Orangutan)	9	6	Blade	Flake	1	Subsistence	Stone			Wright 1972
Pongo pygmaeus (Orangutan)	9	1	Probe	Use stick to pull out insects (termites, ants, bees) and honey from holes in trees (length 9.5-49.5cm, 4.5-15mm thickness). Sticks defoliates, sharpened, split. Very short sticks used with lips.	1, 2, 4	Subsistence	Branch	Twig		van Schaik et al. 1996, Fox & bin'Muhammad 2002; O'Malley & McGrew 2000; Harrisson 1963b, Rijksen 1978, Bourne 1971, Haggerty 1910, Lethmate 1977a, 1977b, 1977d, 1978, Rensch & Dücker 1966, Döhl & Podolczak 1973, Yerkes 1916 in Beck 1980; Galdikas 1982

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pongo pygmaeus (Orangutan)	9	1	Cushion	Padding made out of leaves to protect hands and feet when walking over thorns on branches. Used multiple times.	1	Locomotion, Subsistence	Leaf			Fox & bin'Muhammad 2002
Pongo pygmaeus (Orangutan)	9	1	Probe	Extraction stick used to remove hairs from fruits and pick seeds (length 9.5-20.5cm, thickness 4.6-11mm).	1?	Subsistence	Branch			van Schaik et al. 1996, Fox & bin'Muhammad 2002
Pongo pygmaeus (Orangutan)	9	1	Container	Leaf drinking scoop.	99	Subsistence	Leaf			van Schaik & Knott 2001
Pongo pygmaeus (Orangutan)	9	1	Hook	Branch used to hook branch (length 1-2.5m), not defoliated.	1	Locomotion, Subsistence?	Branch			Fox & bin'Muhammad 2002; Galdikas 1982; Rijksen 1974, 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Scraper	Scratch hard to reach body parts with a branch.	1	Personal hygiene	Stick			Galdikas 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Fishing rod	Use branch to reach fruit, stick to pull something out of a fire, lots of other objects used in captivity to reach food and other stimuli. E.g. separate twigs from branches, bite off splinters, remove bark to improve tool.	1, 2	Subsistence	Branch	other objects		Galdikas 1982; Lethmate 1976b, 1976c, 1976d, 1977a, 1977b, 1977c, 1977d, 1977e, Drescher & Tendelenburg 1927, Ellis 1975, Galdikas-Brindamour 1975, Haggerty 1910, Jantschke 1972, Parker 1968, 1969, Rijksen 1974, 1978, Yerkes 1916, Sheak 1922 in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Digging stick	Dig in ground with sticks. Sticks used as lever when opening termite hills.	99	Subsistence	Stick			Galdikas 1982; Rijksen 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Digging stick	Dig with sticks.	99	Exploration, Game?	Stick			Harrisson 1962, 1963b, Galdikas Brindamour 1975 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Scraper	Use branches and twigs to scratch itself. In captivity and the wild.	1	Personal hygiene	Branch	Twig		Galdikas 1982; Galdikas 1978, Jantschke 1972 in Beck 1980; Galdikas 1982b in Becker 1993
Pongo pygmaeus (Orangutan)	9	2	Hammer	Hit an object to open it.	99	unclear	Stick			Galdikas 1982
Pongo pygmaeus (Orangutan)	9	1	Transport aid	Use stick to transfer prickly durian fruit into cleft to open it. Use stick to remove burning pieces of wood from fire.	99	Subsistence, unclear	Stick			Rijksen 1978, Galdikas-Brindamour 1975 in Beck 1980; Rijksen 1978 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pongo pygmaeus (Orangutan)	9	2	Probe	Poke dead lizard with sick, sniff stick. Stick into deep hole, sniff and lick distal end. Borner - use stick to examine dead animal, probe and sniff.	99	Exploration	Stick			Galdikas 1982; Rijksen 1978, Galdikas-Brindamour 1975 in Beck 1980; Borner pers. com. in Lethmate 1982 in Becker 1993
Pongo pygmaeus (Orangutan)	9	4	Fishing rod	Throw sack onto orange. Throw second sack to pull first sack and orange close.	0	Subsistence	Sack			Reuvens in Yerkes & Yerkes 1929 in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Sponge	Dunk torn off leaves into a narrow container with juice, later such juice from leaves. Leaves also pulled out with twigs. Also used piece of rope as sponge. Plants, fabrics, plastic bags used by animals released in the wild.	1, 3, 4	Subsistence	Leaves	Rope	other objects	Galdikas 1982; Lethmate 1976a, 1976c, 1977a, 1977b, Parker 1968a, 1969, Ellis 1975, Jantschke 1972, MacKinnon 1974b, Thompson pers. com. 1976 in Beck 1980; Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Ladder	Balance sticks and climb them to reach food.	99	Subsistence	Stick			Galdikas 1982; Yerkes 1916 in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Ladder	Balance and climb sticks.	99	Locomotion	Stick			Lethmate 1976c, Rice in Harrisson 1963a in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Ladder	Balance and climb sticks.	99	Game	Stick			Galdikas 1982
Pongo pygmaeus (Orangutan)	9	4	Hammer	Hit one stone onto another stone. When the anvil broke, the splinters were examined closely. Single observation of a male.	0	Game?	Stone			Horwich pers. com. 1973 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Club	Swing stick at food hanging out of reach. Combine up to five sticks to get the right length.	99	Subsistence	Stick			Lethmate 1976c, 1976d, 1977b, 1977e in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Hammer	Hit locks with stones, possibly glass windows (female).	0	Locomotion	Stone			Rijksen 1974 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Hammer	Hit wall and floor of cage as part of a game.	0	Game	Stone			Wright 1972 in Beck 1980; Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Ladder	Lean stick against wall and climb it to reach windows.	99	Locomotion	Stick			Galdikas 1982; Galdikas-Brindamour 1975 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Hammer	Hit wall and floor of cage in frustration.	0	Frustration reduction	Stone			Wright 1972 in Beck 1980; Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Poking stick	Repeatedly poke at hard-skinned fruit with a sharp stick.	99	Subsistence	Stick			Rijksen 1978 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pongo pygmaeus (Orangutan)	9	1	Frond	Break off leafy branch to swipe away wasps and bees. Males? and females.	1	Defense?, Personal hygiene	Branch			Galdikas 1978, Rijksen 1978 in Beck 1980; Rijksen 1978 in Becker 1993
Pongo pygmaeus (Orangutan)	9	2	Lever	Loosen objects stick, metal rods, keys and nails to use them as lever to open a box with food.	99	Subsistence, ?	Stick	other objects		Galdikas 1982; Benchley in Reynolds 1967, Darwin 1871, Ellis 1975, Vosmaer in Yerkes & Yerkes 1929, Yerkes 1916 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Lever	Break away other parts of the cage with a broken off balancing bar. Use lever to bend cage bars, stick head through opening to have better look around.	1	Frustration reduction	Gymnastics bar			Camacho 1907, Hornaday 1934, Benchley in Reynolds 1967, Darwin 1871, Ellis 1975, Vosmaer in Yerkes & Yerkes 1929, Yerkes 1916 in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Optical and audio stimulus	Pull a branch after itself after having seen the body of another orangutan. Disturbed.	1?	Attention	Branch			Rijksen 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Projectile	Aim and throw sticks, stones and other objects at humans, orangutans, and other animals. Rarely in the wild, primarily in captivity and animals to be released to the wild.	99	Threat, Defense	Stick	Stone	other objects	Beeckman in Harrisson 1963a, Harrisson 1963a, Yerkes & Yerkes 1929, Anonym in Kortlandt & Kooij 1963, Rijksen 1974, 1978 in Beck 1980; Beeckman 1718 in Becker 1993
Pongo pygmaeus (Orangutan)	9	2	Poking stick	Poke at humans and orangutans with stick, with a long stick at captive clouded leopard (Neofelis nebulosa).	99	Threat, Defense?	Stick			Galdikas 1982; Rijksen 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Projectile	Break off or drop fresh branches, bark, tendrils, epiphytes, termite tree nests on humans, bothersome monkeys etc. Juveniles and adults of both sexes. Branches from a few cm to a few meters long for a period of up to 15 min.	1	Threat, Defense	Branch	Bark	other objects	Davenport 1967, Galdikas 1975, 1978, Harrisson 1963a, 1963b, Schneider in Harrison 1963a, MacKinnon 1971, 1974a, 1974b, Rijksen 1978, Schaller 1961, Schultz 1961, Wallace 1869, Horr 1975, 1977 in Beck 1980; Rijksen 1978, Radermacher 1780 in Becker 1993
Pongo pygmaeus (Orangutan)	9	4	Projectile	Aimed throwing as part of game.	99	Game	?			Harrisson 1963a in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Optical stimulus	Swing branch at humans, sticks at dogs.	99	Impress, Threat	Branch			Galdikas pers. com. 1977, Galdikas 1975, Rijksen 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Club	Throw potted plant at skylight to escape.	0	Locomotion, Subsistence	Potted plant			Boulenger 1936 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pongo pygmaeus (Orangutan)	9	1	Club	Hit other orangutans, snakes, lizards, and humans with pieces of bark, small trees, sacks, and branches. In captivity and wild.	1	Threat, Defense?	Stick	other objects		; Galdikas 1982; Rijksen 1978, Galdikas 1978, Harrisson 1963b, Rabb pers. com. 1971 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Club	Hit walls and floors with sacks and other objects in anger.	99	Frustration reduction	Sack	other objects		Jantschke 1972 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Fishing rod	Leaf risps as reaching tool.	2	Subsistence	Leaf			Dittmar in Ellis 1975, Lethmate 1976a, 1976c, 1977a, 1977b in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Stick for stirring	Stir (hot) liquids.	99	Subsistence	Stick			Galdikas 1982
Pongo pygmaeus (Orangutan)	9	2	Paddle	Use stick to paddle, pole or cast off canoe.	99	Locomotion	Stick			Galdikas 1982
Pongo pygmaeus (Orangutan)	9	2	Fork	Use stick to eat food (like fork or spoon).	99	Subsistence	Stick			Galdikas 1982
Pongo pygmaeus (Orangutan)	9	2	Instrument for cleaning	Use stick to remove stinging insects from fur.	99	Personal hygiene	Stick			Galdikas 1982
Pongo pygmaeus (Orangutan)	9	2	Bridge	Tree trunks and vines brought to a crossing point to build a bridge and cross a river.	99	Locomotion	Tree trunk	Plant tendril		Galdikas 1982
Pongo pygmaeus (Orangutan)	9	2	Raft	Use tree stump, canoe, and raft to cross a river. In part, untied. A male frequently used a boat and held the rope while pursuing other activities in order to use it later.	1	Locomotion	Tree trunk	Raft	Boat	Galdikas 1982
Pongo pygmaeus (Orangutan)	9	1	Cover	Cover with twigs to protect from bees. Single observation of a female.	1?	Protection	Twig			Rijksen 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Cover	Cover the head and neck with plant matter when other animals approach.	1?	unclear	Plant			Rijksen 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Cover	Cover its own body in the presence of humans. Hiding? Branches broken off.	1	Protection, Hiding place?	Branches	Plant material		MacKinnon 1974b in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Cover	Protection from rain and sun through a cover of large leaves and other plant matter. Branches broken off.	1?	Personal hygiene	Leaves	Other plant materials		MacKinnon 1971, 1974a, 1974b, Rijksen 1978, Galdikas 1975, 1978, Wallace 1869 in Beck 1980; Rijksen 1978 in Becker 1993

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pongo pygmaeus (Orangutan)	9	4	Swinging rope	Fabric hung near the top of the cage, used as swinging rope.	0	Locomotion, Game	Fabric			Beck 1980
Pongo pygmaeus (Orangutan)	9	5	Ladder	Stack up to four boxes to reach food hung out of reach.	3	Subsistence	Boxes			Lethmate 1976 c, 1976d, 1977a, 1977b, Yerkes 1916 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Ladder	Stack chairs on a table to climb on them.	3	Game	Table	Chair		Rensenbrink 1960 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Swinging rope	Twist straw into a rope (over 2m long) and use it to swing.	3, 4	Locomotion, Game	Straw			Gewalt 1975, Hornaday 1934, Jantschke 1972, MacKinnon 1978 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Cover	Drape fabric, leaves, branches, rope, chains, food, and straw and paper over head and back as part of a game. Individually or with other objects. Wild animals, animals to be released to the wild and in captivity. Wild: break off branches.	1	Game	Fabric	Straw	other objects	Galdikas 1982; MacKinnon 1974a, 1974b, Freeman & Alcock 1973, Harrisson 1962, 1963a, Jantschke 1972, Darwin 1871 in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Container	Coconut halves, pieces of a tire and hollow objects used as containers for water and milk. Animal either drinks directly from container or solid food is soaked in it to soften it.	0	Subsistence	Pieces of a tire	Coconut halves	other objects	Galdikas 1982; Beck 1980; Ellis 1975 in Beck 1980
Pongo pygmaeus (Orangutan)	9	2	Container	Fill a concave piece of bark with rice to pass it on, fill a large pipe with straw, carry it to outside cage to build a nest, small containers used to carry liquids.	0	Transport	Pipes	Bark		Galdikas 1982; Beck 1980; Ellis 1975, O'Connor pers. com. 1976 in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Rag	Wipe fecal matter from fur, spit from mouth, face and arms. Wipe medicine from face - among captive animals (male and female) using fabric, fresh leaves, mud, and plant matter.	1?	Personal hygiene	Leaf	other objects		Galdikas 1982; MacKinnon 1974b, Rijksen 1978 in Beck 1980; Rijksen 1978 in Becker 1993
Pongo pygmaeus (Orangutan)	9	4	Social stimulus	Rub other animals' penises with orange peals etc.	0	Stimulation?	Orange peels	other objects		Harrisson 1962 in Beck 1980
Pongo pygmaeus (Orangutan)	9	4	Cover	Cover head and back with fabric, paper, and straw before going to sleep.	99	Personal hygiene, Protection?	Fabric	Paper	Straw	Beck 1980; Bourne 1971, Harrisson 1963a, 1963b in Beck 1980
Pongo pygmaeus (Orangutan)	9	1	Rag	Wipe faces with balled up leaves. Frustration?	1, 4	Frustration reduction	Leaves			Galdikas 1982; Galdikas 1978 in Beck 1980

Animal species	Group	Situation	Artifact	Description	Modification	Function	RM 1	RM 2	RM 3	Literature
Pongo pygmaeus (Orangutan)	9	1	Cover	Use leaves to wrap an ant net (torn from a branch) to protect itself from bites while eating? Wrap up prickly fruits with paper, leaves, and fabric - animals to be returned to the wild.	1	Protection	Leaves	Paper	Sack	Rijksen 1978 in Beck 1980; Rijksen 1978 in Becker 1993
Pongo pygmaeus (Orangutan)	9	1	Stimulation	Rub and wipe its own genitals with a living (cat) and other objects (orange peal). Wild animals, animals to be returned to the wild and animals in captivity.	0	Stimulation	Cat	Orange peels	other objects	Rijksen 1978, Harrisson 1962 in Beck 1980

Appendix II Early Lower Paleolithic Find Sites of the Oldowan Techno-complex

Find site	Dating	Artifact	Artifact use	Hominids	Literature
Bouri, Ethiopia	2.5 MA	---	Cut and slash marks on bones	Australopithecus garhi	deHeinzelin et al. 1999
Ounda Gona, OGS-6, Ethiopia	2.6-2.5 MA	Stone artifacts, surface inventory	Cut marks on bones	---	Semaw et al. 2003; Domínguez-Rodrigo et al. 2005
Ounda Gona, OGS-7, Ethiopia	2.6-2.5 MA	2.6 m² excavated, flakes, heavily exhausted cores, debris, circa 500 artifacts in situ, 200 from the surface, local raw materials selected, partially retouched	Slash marks on bones	---	Semaw et al. 2003; Domínguez-Rodrigo et al. 2005
Dana Aoule, DAN1, Ethiopia	2.6-2.5 MA	Two horizons with stone artifacts	---	---	Domínguez-Rodrigo et al. 2005
KadaGona, EG-10, Ethiopia	2.6-2.5 MA	13 m², 2970 artifacts (with EG 12), cores, flakes, debris, hammer stones, no retouch, primarily local raw material: trachyte	---	---	Semaw et al. 1997
Kada Gona, EG-12, Ethiopia	2.6-2.5 MA	9 m², 2970 artifacts (with EG 10) cores, flakes, debris, hammer stones, no retouch, primarily local raw material: trachyte	---	---	Semaw et al. 1997
Kada Gona, EG-13, Ethiopia	2.6-2.5 MA		One bone with cut marks	---	Semaw et al. 2002; Domínguez-Rodrigo et al. 2005
Kada Gona, WG1, Ethiopia				---	Domínguez-Rodrigo et al. 2005
Kada Gona, WG9, Ethiopia	2.5 MA		Two bones with cut marks	---	Semaw 2000; Domínguez-Rodrigo et al. 2005

Find site	Dating	Artifact	Artifact use	Hominids	Literature
Busidima, BSN6, Ethiopia	2.0-2.5 MA	Cores, debris	---	---	Domínguez-Rodrigo et al. 2005
Hadar, Afar Locality 666, Ethiopia	2.33 ± 0.07 MA	34 stone tools, 14 in situ from 1.25 x 2m (80cm deep). Primarily basalt and flint, primarily flakes	Bones with modifications by humans? Bovid shoulder blade with cut marks?	Homo habilis?	Kimbel et al. 1996
Omo 57, Member F, Shungura Formation, Ethiopia	2.34-2.32 MA redeposited?			---	Howell et al. 1987
Omo 123, Member F, Shungura Formation, Ethiopia	2.34-2.32 MA redeposited?	Raw material primarily quartz, transport over multiple kilometers (20km?)	Bones are rare	---	Howell et al. 1987
Omo FtJj2, Member F, Shungura Formation, Ethiopia	2.34-2.32 MA redeposited?	Raw material primarily quartz, transport over multiple kilometers (20km?)	No bones	---	Howell et al. 1987
Omo FtJj5, Member F, Shungura Formation, Ethiopia	2.34-2.32 MA redeposited?			---	Howell et al. 1987
Omo FtJj1, Member F, Shungura Formation, Ethiopia	2.34-2.32 MA redeposited?			---	Howell et al. 1987
(**Omo 71**, Member E, Shungura Formation, Ethiopia)	2.48-2.36 MA Surface inventory			---	Howell et al. 1987
(**Omo 84**, Member E, Shungura Formation, Ethiopia)	2.48-2.36 MA unclear stratigraphy			---	Howell et al. 1987

Find site	Dating	Artifact	Artifact use	Hominids	Literature
Lokalalei L1A (GaJh5), Nachukui Formation West Turkana, Kenya	2.34 MA ± 0.05 MA	14 m², 31 artifacts, flakes, barely exhausted cores, debris, local raw material	Poss. 2 cut marks, 1 blow mark	---	Kibunjia et al. 1992, Kibunjia 1994, Roche et al. 1999, Brown & Gathogo 2002
Lokalalei L2C Nachukui Formation West Turkana, Kenya	2.34 ± 0.05 MA, ca. 2.24 MA	17 m², ca. 3000 artifacts, refits 60 artifact sets, up to 51 flakes per core, ca. 20 retouched, 129 artifacts/m²	No marks on bones	---	Roche et al. 1999, Brown & Gathogo 2002, Delagnes & Roche 2005
Senga 5°, Semliki River, Republic of the Congo	2-2.3 MA (Date is problematic)	in limonite sediment. 435 stone artifacts excavated, 295 collected from surface, cores, flakes, debris. 97% quartz, local (< 1 km)	Numerous animal bones associated, cut marks?	----	Harris et al. 1987
Dana Aoule, DAN2, Ethiopia	2.1 –2.27 MA	Hundreds of stone artifacts on the surface, numerous in situ	Cut marks on five bones	---	Domínguez-Rodrigo et al. 2005
Kanjera South, Excavation 1, Kenya	> 2.15 MA	41 m²; 1435 stone artifacts recorded, additional artifacts in sieves, partially relocated due to fluvial activities, 15% of raw material in a random sample not of local origin	Numerous animal bones associated, cut marks?	---	Plummer et al. 1999
Kanjera South, Excavation 2, Kenya	> 2.15 MA	15 m²; 214 stone tools, 5 of these in situ next to partial skeleton. Raw material local and transported, cores, flakes	Associated partial skeleton of hippopotamus, cut marks?	---	Plummer et al. 1999
Olduvai Gorge West, Trench 57, upper Bed I, Tanzania	1.839 ± 0.005 MA – 1.785 MA	234 stone artifacts, 92% local quartzite, 3 pieces of lave from 15-20km away, Oldowan cores	4.2% of bones with cut marks, 8.3% with blow marks	OH 65 Homo habilis (Homo rudolfensis?)	Blumenshine et al. 2003

Find site	Dating	Artifact	Artifact use	Hominids	Literature
DK, Lower Bed I Olduvai Gorge, Tanzania	1.8 – 1.75 MA	Cores, core tools, flakes, hammer stones, manuports, round stone formations originally interpreted as housing		OH 24	Leakey 1971
FLK-NN, Lower und Middle Bed I Olduvai Gorge, Tanzania	1.8 – 1.75 MA	Cores, core tools, flakes, hammer stones, manuports		OH 4, 7, 8	Leakey 1971, Walter et al. 1991
FLK-22 (Zinj), Middle Bed I Olduvai Gorge, Tanzania	1.8 – 1.75 MA	Cores, core tools, 2275 flakes, hammer stones, manuports from Zinjanthropus floor		Australopithecus boisei (Zinj, OH 5)	Leakey 1971, Walter et al. 1991
FLK North, Upper Bed I und Lower Bed II Olduvai Gorge, Tanzania	1.8 – 1.75 MA and younger?	Elephant skeleton: 123 artifacts Deinotherium skeleton: 39 artifacts + additional cores, core tools, flakes, hammer stone, manuports	Elephant and deinotherium skeletons with associated artifacts	OH 10, 16	Leakey 1971
Kokiselei (FxJh5), Nachukui Formation, West Turkana, Kenya	1.8 ± 0.1 MA	5 m², 316 artifacts, cores, flakes, debris, local raw material	One bone with cut marks	---	Kibunjia et al. 1992
Nayiena Engol, (FxJh6), Nachukui Formation, West Turkana, Kenya	1.8 ± 0.1 MA	2m², 109 artifacts, cores, flakes, debris, local raw material		---	Kibunjia et al. 1992
Koobi Fora, East Rudolf, Kenya **KBS site, FxJj1**	ca. 1.8 MA or older	KBS industry, 139 stone tools in situ, 60-70 from surface, flakes, debris, cores, on-site production, raw materials transported 10-15km	Broken apart animal bones, different animal species	Not direct, only in the immediate vicinity	Isaac & Harris 1978

Find site	Dating	Artifact	Artifact use	Hominids	Literature
Koobi Fora, East Rudolf, Kenya **HAS site, FxJj3**	ca. 1.8 MA or older	KBS industry, 118 stone tools in situ, ca. 50 from surface, flakes, debris, cores, hammer stones, on-site production, raw material transported 10-15km	Bones from a single hippopotamus	---	Isaac & Harris 1978
Koobi Fora, East Rudolf, Kenya **NMS site, FxJj10**	ca. 1.8 MA or older	KBS industry, 306 stone artifacts, raw material transported 10-15km	No bones	---	Isaac & Harris 1978
Koobi Fora, East Rudolf, Kenya **North-west site, FxJj38 N-W**	ca. 1.8 MA or older	KBS industry		KNM-ER 1805 (*Homo habilis*?) and 1806 (*A. boisei*) in the near vicinity	Isaac & Harris 1978
Melka Kunture, Ethiopia	< 1,8 MA				Chavaillon et al. 1979
Sterkfontein, South Africa	1.7-2.0 MA	3246 artifacts, raw material within a 300m radius		Homo habilis?	Kuman 2003
Swartkrans, Member 1, South Africa	1.7-1.8 MA	17 bones digging instruments, 402 stone artifacts, raw materials within a 300m radius		Australopithecus robustus, Homo	Brain 1993b, Clark 1993, Kuman 2003
Kroomdrai B, South Africa	1.7-2.0 MA	2 secure stone artifacts, raw material within 300m		---	Kuman 2003
Dmanisi, Georgia	1,7-1,85 Ma	> 1000 artefakts: few choppers, chopping tools, few scrapers, many flakes, raw material local basalt		Homo ergaster, Homo georgicus	Ferring et al. 2011
Mwimbi, Chiwondo Beds, Malawi	> 1.6 MA	27 stone tools, flakes, core tools		---	Kaufulu & Stern 1987
MNK skull site, Lower part Middle Bed II	< 1.7 MA	Core tools, flakes		OH 13, 14, 15	Leakey 1971

Find site	Dating	Artifact	Artifact use	Hominids	Literature
MNK Chert Factory Site, Olduvai Gorge Bed II, Tanzania	Ca. 1.6 MA	30.000 stone artifacts, primarily flint, lava, quartz/quartzite, raw material in part brought in 1km, up to 1km away		---	Stiles 1991, Leakey 1971
HWK-E 3-4, Lower part of Middle Bed II Olduvai Gorge, Tanzania	Ca. 1.6 MA	1989 stone artifacts, selected flint, raw material (flint, lava, gneiss, gabbro) transported min. 1 km	No cut marks on animal bones	---	Stiles 1991, Leakey 1971
Peninj ST site complex, Tanzania	1.6-1.4 MA	352 artifacts at 11 locations, raw material (basalt, quartz, nephelinite) tested, transported min. 3.2km, core tools, flakes, debris, hammer stones		---	de la Torre et al. 2003

References

Aiello, Leslie C. & Peter Wheeler 1995. The expensive-tissue hypothesis. The brain and the digestive system in human and primate evolution. Current Anthropology 36/2, 199-221.

Albrecht, Gerd, Heidi Engelhardt, Hansjürgen Müller-Beck, Günther Unrath & I. Yalcinkaya 1984. Vorbericht über die Untersuchungen an der Faustkeilstation Şehremuz in der südöstlichen Türkei. Eiszeitalter und Gegenwart 34, 43-86.

Alp, Rosalind 1997. “Stepping-sticks” and “seat-sticks”: new types of tools used by wild chimpanzees (Pan troglodytes) in Sierra Leone. American Journal of Primatology 41, 45-52.

Alsberg, Paul 1922. Das Menschheitsrätsel. Versuch einer prinzipiellen Lösung. Dresden: Sibyllen.

Anderson-Gerfaud, Patricia 1990. Aspects of behaviour in the Middle Palaeolithic: Functional analysis of stone tools from southwest France. In Paul Mellars (Hrsg.), The emergence of modern humans. An archaeological perspective. Edinburgh: Edinburgh University Press, 389-418.

Asfaw, Berhane, Yonas Beyene, Gen Suwa, Robert C. Walter, Tim D. White, Giday WoldeGabriel & Tesfaye Yemane 1992. The earliest Acheulean from Konso-Gardula. Nature 360, 732-735.

Ashton,Nick & John McNabb 1994. Bifaces in perspective. In Nick Ashton & Andrew David (Hrsg.), Stories in stone. London: Lithic Studies Society Occasional Paper No. 4, 182-191.

Asserson, Clea, Andrew Whiten, Zephyr T. Kiwede, John Tinka & Joseph Karamagi 2004. Use of leaves to inspect ectoparasites in wild chimpanzees: a third cultural variant? Primates 45, 255-258.

Avery, G. 1988. Some features distinguishing various types of occurrence at Elandsfontein, Cape Province, South Africa. In K. Heine (Hrsg.), Paleoecology of Africa Vol. 19.

Baber, Christopher 2003. Cognition and tool use. Forms of engagement in human and animal use of tools. London, New York: Taylor & Francis.

Backwell, L. R. & Francesco D’Errico 2001. Evidence of termite foraging by Swartkrans early hominids. Proceedings of the National Academy of Sciences USA 98/4, 1358-1363.

Badrian, Noël, Alison Badrian & Randall L. Susman 1981. Preliminary observations on the feeding behavior of *Pan paniscus* in the Lomako forest of central Zaïre. Primates 22/2, 245-251.

Balter, Michael 2002. What made humans modern? Science 295, 1219-1225.

Barham, Lawrence S. 2002. Systematic pigment use in the Middle Pleistocene of south central Africa. Current Anthropology 43/1, 181-190.

Barham, L. S., A. C. Pinto Llona & C. B. Stringer 2002. Bone tools from Broken Hill (Kabwe) cave, Zambia, and their evolutionary significance. Before Farming 2/3, 1-16.

Beck, Benjamin B. 1974. Baboons, chimpanzees, and tools. Journal of Human Evolution 3/6, 509-516.

Beck, Benjamin B. 1980. Animal tool behavior. The use and maufacture of tools by animals. New York, London: Garland STPM Press.

Beck, Benjamin B. 1982. Chimpocentrism: bias in cognitive ethology. Journal of Human Evolution 11/1, 3-17.

Becker, Peter-René 1993. Werkzeuggebrauch im Tierreich. Stuttgart: S. Hirzel Wissenschaftliche Verlagsgesellschaft.

Bednarik, Robert G. 1999. Der Kiesel von Makapansgat. Früheste Urkunst der Welt? Anthropos 94, 199-204.

Bednarik, Robert G. 2003. A figurine from the African Acheulian. Current Anthropology 44/3, 405-413.

Belfer-Cohen, Anna & Naama Goren-Inbar 1994. Cognition and communication in the Levantine Lower Palaeolithic. World Archaeology 26/2, 144-157.

Belitzky, S., Naama Goren-Inbar & Ella Werker 1991. A Middle Pleistocene wooden plank with man-made polish. Journal of Human Evolution 20, 349-353.

Bender, Barbara 1993. Cognitive archaeology and cultural materialism. In Viewpoint: What is cognitive archaeology? Cambridge Archaeological Journal 3/2, 247-270.

Berthelet, A. & J. Chavaillon (Hrsg.) 1993. The use of tools by human and non-human primates. A Fyssen Foundation Symposium. Oxford: Clarendon Press.

Beyries, S. & Frédéric Joulian 1990. L'utilisation d'outils chez les animaux: Chaînes opératoires et complexité technique. Paléo 2, 17-26.

Bickerton, Derek 1995. Language and human behaviour. Seattle: University of Washington Press.

Binford, L. R. 1979. Organization and formation processes: Looking at curated technologies. Journal of Anthropological Research 35, 255-273.

Binford, L. R. 1989. Isolating the transition to cultural adaptations: an organizational approach. In Erik Trinkaus (Hrsg.), The Emergence of modern humans: biocultural adaptations in the Later Pleistocene. Cambridge: Cambridge University Press, 18-41.

Binneman, J. & P. Beaumont 1992. Use-wear analysis of two acheulean handaxes from Wonderwerk Cave, Northern Cape. Southern African Field Archaeology 1, 92-97.

Blumenshine, Robert J., Charles R. Peters, Fidelis T. Masao, Ronald J. Clarke, Alan L. Deino, Richard L. Hay, Carl C. Swisher, Ian G. Stanistreet, Gail M. Ashley, Lindsay J. McHenry, Nancy E. Sikes, Nikolaas J. van der Merwe, Joanne C. Tactikos, Amy E. Cushing, Daniel M. Deocampo, Jackson K. Njau & James I. Ebert 2003. Late Pliocene Homo and homind land use from Western Olduvai Gorge, Tanzania. Science 299, 1217-1221.

Boëda, Eric 1990. De la surface au volume. In C. Farizy (Hrsg.), Paléolithique moyen récent et Paléolithique supérieur ancien en Europe. Ruptures et transitions: examen critique des documents archaéologiques. Actes du colloques international de Nemours 1988. Mémoires du Musée de Préhistoire d'Ile-de-France,

Boëda, E., J. Connan, D. Dessort, S. Muhesen, N. Mercier, H. Valladas & N. Tisnérat 1996. Bitumen as hafting material on Middle Paleolithic artefacts. Nature 380, 336-338.

Boëda, Eric, Jean-Michel Geneste & C. Griggo with N. Mercier, S. Muhesen, J. L. Reyss, A. Taha & H.Valladas 1999. A Levallois point embedded in the vertebra of a wild ass (*Equus africanus*): hafting, projectiles and Mousterian hunting weapons. Antiquity 73, 394-402.

Boëda, Eric, Jean-Michel Geneste & Liliane Meignen 1990. Identification de chaînes opératoires lithiques du Paléolithique Ancien et Moyen. Paléo 2, 43-80.

Boesch, Christophe 1991. Teaching among wild chimpanzees. Animal Behavior 41, 530-532.

Boesch, Christophe & Hedwige Boesch 1981. Sex differences in the use of natural hammers by wild chimpanzees. A preliminary report. Journal of Human Evolution 10, 585-593.

Boesch, Christophe & Hedwige Boesch 1983. Optimization of nut-cracking with natural hammers by wild chimpanzees. Behaviour 83, 265-286.

Boesch, Christophe & Hedwige Boesch 1984a. Possible causes of sex differences in the use of natural hammers by wild chimpanzees. Journal of Human Evolution 13, 415-440.

Boesch, Christophe & Hedwige Boesch 1984b. Mental map in wild chimpanzees. An analysis of hammer transports for nut cracking. Primates 25, 160-170.

Boesch, Christophe & Hedwige Boesch 1989. Hunting behavior of wild chimpanzees in the Taï National Park. American Journal of Physical Anthropology 78, 547-573.

Boesch, Christophe & Hedwige Boesch 1990. Tool use and tool making in wild chimpanzees. Folia Primatologica 54, 86-99.

Boesch, Christophe & Michael Tomasello 1998. Chimpanzee and human culture. Current Anthropology 39, 591-614.

Bolk, Louis 1926. Das Problem der Menschwerdung. Jena: Gustav Fischer.

Bolus, Michael & Oliver Rück 2000. Eine Blattspitze aus Wittislingen, Lkr. Dillingen a.d. Donau (Bayern). Zur südwestlichen Verbreitungsgrenze spätmittelpaläolithischer Blattspitzeninventare. Archäologisches Korrespondenzblatt 30/2, 165-172.

Borgia, G. 1985. Bower quality, number of decorations and mating success of male satin bowerbirds (*Ptilonorhynchus violaceus*): an experimental analysis. Animal Behaviour 33, 266-271.

Borgia, G.,S. G. Pruett-Jones & M.A. Pruett-Jones 1985. The evolution of bower-building and the assessment of male quality. Zeitschrift für Tierpsychologie 67, 225-236.

Borsari, Andressa & Eduardo B. Ottoni 2005. Preliminary observations of tool use in captive hyacinth macaws (*Anodorhynchus hyacinthinus*). Animal Cognition 8, 48-52.

Boswall, Jeffery 1977. Tool-using by birds and related behaviour. Avicultural Magazine (London) 83, 88-97, 146-159, 220-228.

Boysen, Sarah T., Valerie A. Kuhlmeier, Peter Halliday & Yolanda M. Halliday 1999. Tool use in captive gorillas. In Parker, Sue Taylor, Robert W. Mitchell & H. Lyn Miles (Hrsg.), The mentalities of gorillas and orangutans: comparative perspectives. Cambridge, Cambridge University Press, 179-187.

Brain, C. K. (Hrsg.) 1993a. Swartkrans. A cave's chronicle of early man. Transvaal Museum Monograph No.8. Pretoria: Transvaal Museum.

Brain, C. K. 1993b. The occurrence of burnt bones at Swartkrans and their implications for the control of fire by early hominids. In C. K. Brain (Hrsg.), Swartkrans. A cave's chronicle of early man. Transvaal Museum Monograph No.8. Pretoria: Transvaal Museum, 229-242.

Brain, C. K. 1993c. A taphonomic overview of the Swartkrans fossil assemblages. In C. K. Brain (Hrsg.), Swartkrans. A cave's chronicle of early man. Transvaal Museum Monograph No.8. Pretoria: Transvaal Museum, 257-264.

Brain, C.K. & Pat Shipman 1993. The Swartkrans bone tools. In C. K. Brain (Hrsg.), Swartkrans. A cave's chronicle of early man. Transvaal Museum Monograph No.8. Pretoria: Transvaal Museum, 195-215.

Bratlund, Bodil 1990. Rentierjagd im Spätglazial. Eine Untersuchung der Jagdfrakturen an Rentierknochen von Meiendorf und Stellmoor, Kreis Storman. Offa 47, 7-34.

Braun, David R., Joanne C. Tactikos, Joseph V. Ferraro & J. W.K. Harris 2005. Flake recovery rates and inferences of Oldowan hominin behavior:a response to Kimura 1999, 2002. Journal of Human Evolution 48, 525-531.

Breuer, Thomas, Mireille Ndoundou-Hockemba & Vicki Fishlock 2005. First observation of tool use in wild gorillas. PloS Biology 3/11, e380.

Brewer, Stella M. & W. C. McGrew 1990. Chimpanzee use of a tool-set to get honey. Folia Primatologica 54, 100-104.

Britten, Roy J. 2002. Divergence between samples of chimpanzee and human DNA sequences is 5%, counting indels. Proceedings of the National Academy of Science 99/21, 13633-13635.

Brooks, Alison S., David M. Heögren, Jon S. Cramer, Alan Franklin, William Hornyak, Jody M. Keating, Richard G. Klein, William J. Rink, Henry Schwarcz, J. N. Leith Smith, Kathlyn Stewart, Nancy E. Todd, Jacques Verniers & John E. Yellen 1995. Dating and context of three Middle Stone Age sites with bone points in the Upper Semliki Valley, Zaire. Science 268, 548-553.

Brown, P., T. Sutikna, M. J. Morwood, R. P. Soejono, Jatmiko, E. Wayhu Saptomo & Rokus Awe Due 2004. A new small-bodied human from the Late Pleistocene of Flores, Indonesia. Nature 431, 1055-1061.

Brunet, Michel, Franck Guy, David Pilbeam, Hassane Taisso Mackaye, Andossa Likius, Djimdoumalbaye Ahounta, Alain Beauvilain, Cécile Blondel, Hervé Bocherens, Jean-Renaud Boisserie, Louis de Bonis, Yves Coppens, Jean Dejax, Christiane Denys, Philippe Duringer, Véra Eisenmann, Gongdibé Fanone, Perre Fronty, Denis Geraads, Thomas Lehmann, Fabrice Lihoreau, Antoine Louchart, Adoum Mahamat, Gildas Merceron, Guy Mouchelin, Olga Otero, Pablo Pelaez Campomanes, Marcia Ponce de Leon, Jean-Claude Rage, Michel Sapanet, Mathieu Schuster, Jean Sudre, Pascal Tassy, Xavier Valentin, Patrick Vignaud, Laurent Viriot, Antoine Zazzo & Christoph Zollikofer 2002. A new hominid from the Upper Miocene of Chad, Central Africa. Nature 418, 145-151.

Byrne, Richard W. 1996. The misunderstood ape: Cognitive skills of the gorilla. In Russon, Anne E., Kim A. Bard & Sue Taylor Parker (Hrsg.), Reaching into thought. The minds of the great apes. Cambridge: Cambridge University Press, 111-130.

Byrne, Richard W. 1999. Object manipulation and skill organization in the complex food preparation of mountain gorillas. In Parker, Sue Taylor, Robert W. Mitchell & H. Lyn Miles (Hrsg.), The mentalities of gorillas and orangutans: comparative perspectives. Cambridge: Cambridge University Press, 147-159.

Calvin, William. H. 1993. The unitary hypothesis: a common neural circuitry for novel manipulations, language, plan-ahead, and throwing? In Kathleen R. Gibson & Tim Ingold (Hrsg.), Tools, language and cognition in human evolution. Cambridge: Cambridge University Press, 230-250.

Cantalupo, Claudio & William D. Hopkins 2001. Asymmetric Broca's area in great apes. Nature 414, 505.

Carbonell, E., J. M. Bermúdez de Castro, J. L. Arsuaga, J. C. Diez, A. Rosas, G. Cuenca Bescós, R. Sala, M. Mosquera & X. P. Rodríguez 1995. Lower Pleistocene hominids and artifacts from Atapuerca-TD6 (Spain). Science 269, 826-830.

Carbonell, E & Z. Castro-Curel 1992. Paleolithic wooden artefacts from the Abric Romaní (Capellades, Barcelona, Spain). Journal of Archaeological Science 19, 707-719.

Caro, T.M. & M. D. Hauser 1992. Is there teaching in nonhuman animals? Quaterly Review of Biology 67, 151-174.

Cela-Conde, Camilo 1998. The problem of hominoid systematics, and some suggestions for solving it. South African Journal of Science 94, 255-262.

Cela-Conde, Camilo J. & Gisèle Marty 1997. Mind architecture and brain architecture. Biology and Philosophy 12, 327-340.

Chavaillon, J., N. Chavaillon & F. Hours 1979. From the Oldowan to the Middle Stone Age at Melka Kunture (Ethiopia): understanding cultural changes. Quaternaria 21, 87-114.

Chevalier-Skolnikoff, Suzanne 1990. Tool use by wild *Cebus* monkeys at Santa Rosa National Park, Costa Rica. Primates 31/3, 375-383.

Chevalier-Skolnikoff, Suzanne & Jo Liska 1993. Tool use by wild and captive elephants. Animal Behaviour 46/2, 209-219.

Chiang, Mickey 1967. Use of tools by wild macaque monkeys in Singapore. Nature 214, 1258-1259.

Chomsky, Noam 1980. Rules and representations. The Behavioral and Brain Sciences 3, 1-61.

Clark, J. D. 2001. Modified, used and other wood specimens from Acheulian horizons. In

Clark, J. D. (Hrsg.) 2001, Kalambo Falls Prehistoric Site Vol. III. Cambridge: Cambridge University Press.

Collias, N. & E. Collias 1976. External construction by animals. Stroudsburg/Pa: Dowden, Hutchinson and Ross.

Collins, Michael B. 1973. Observations on the thermal treatment of chert in the Solutrean of Laugerie Haute, France. Proceedings of the Prehistoric Society 39, 461-466.

Comte, Auguste 1853. Système de politique positive on traité de sociologie. Troisième volume (Tome troisième contenant la dynamique sociale ou le traité général du progrès humain). Nachdruck 1970, Paris: éditions anthropos.

Conard, Nicholas J. 2003. Palaeolithic ivory sculptures from southwestern Germany and the origins of figurative art. Nature 426, 830-832.

Conard, Nicholas J. & Michael Bolus 2003. Radiocarbon dating the appearance of modern humans and timing of cultural innovations in Europe: new results and new challenges. Journal of Human Evolution 44, 331-371.

Conard, Nicholas J., Pieter M. Grootes & Fred H. Smith 2004. Unexpectedly recent dates for human remains from Vogelherd. Nature 430, 198-201.

Connolly, Kevin & Mary Dalgleish 1989. The emergence of a tool-using skill in infancy. Developmental Psychology 25/6, 894-912.

Coolidge, Frederick L. & Thomas Wynn 2001. Executive functions of the frontal lobes and the evolutionary ascendancy of *Homo sapiens*. Cambridge Archaeological Journal 11/2, 255-260.

Coqueugniot, H., J.-J Hublin, F. Veillon, F. Houët & T. Jacob 2004. Early brain growth in Homo erectus and implications for cognitive ability. Nature 431, 299-302.

D'Amore, Guiseppe, Patrizio Frederic & Václav Vančata 2001. Process of encephalization in hominid evolution: preliminary results of biostatistic analysis of brain size phylogenetic changes. Anthropologie 39/2-3, 215-226.

Davidson, Iain & William Noble 1993. Tools and language in human evolution. In Kathleen R. Gibson & Tim Ingold (Hrsg.), Tools, language and cognition in human evolution. Cambridge: Cambridge University Press, 363-388

Deacon, Terrence W. 1990. Fallacies of progression in theories of brain-size evolution. International Journal of Primatology 11/3, 193-236.

Deacon, Terrence W. 1994a. The human brain. In Jones, Steve, Robert Martin & David Pilbeam (Hrsg.), The Cambridge encyclopedia of human evolution. Cambridge: Cambridge University Press, 115-123

Deacon, Terrence W. 1994b. Biological aspects of language. In Jones, Steve, Robert Martin & David Pilbeam (Hrsg.), The Cambridge encyclopedia of human evolution. Cambridge: Cambridge University Press, 128-133.

Dean, Christopher, Meave G. Leakey, Donald Reid, Friedemann Schrenk, Gary T. Schwartz, Christopher Stringer & Alan Walker 2001. Growth processes in teeth distinguish modern humans from *Homo erectus* and earlier hominins. Nature 414, 628-631.

d'Errico, Francesco 2003. The invisible frontier. A multiple species model for the origin of behavioral modernity. Evolutionary Anthropology 12, 188-202.

d'Errico, Francesco, Christopher Henshilwood, Graeme Lawson, Marian Vanhaeren, Anne Marie Tillier, Marie Soressi, Frédérique Bresson, Bruno Maureille, April Nowell, Joseba Lakarra, Lucinda Backwell & Michèle Julien 2003. Archaeological evidence for the emergence of language, symbolism, and music – an alternative multidisciplinary perspective. Journal of World Prehistory 17/1, 1-70.

d'Errico, Francesco, Christopher Henshilwood & Peter Nilssen 2001. An engraved bone fragment from c. 70,000-year-old Middle Stone Age levels at Blombos Cave, South Africa: implications for the origin of symbolism and language. Antiquity 75, 309-318.

d'Errico, F., M. Julien, D. Liolios, M. Vanhaeren & D. Baffier 2003. Many awls in our argument: bone tool manufacture and use in the Châtelperronien and Aurignacian levels of the Grotte du Renne at Arcy-sur-Cure. In J. Zilhão & F. d'Errico (Hrsg.), The chronology of the Aurignacian and of the transitional technocomplexes: dating, stratigraphies, cultural implications. Proceedings of Symposium 6.1 of the 14th Congress of the UISPP. Lisbon: Instituto Portugês de Arquelogia, 247-270.

d'Errico, Francesco & April Nowell 2000. A new look at the Berekhat Ram figurine: implications for the origins of symbolism. Cambridge Archaeological Journal 10/1, 123-167.

d'Errico, F., J. Zilhão, D. Baffier, M. Julien & J. Pelegrin 1998. Neandertal acculturation in western Europe? A critical review of the evidence and its interpretation. Current Anthropology 39, S1-S44.

Delagnes, Anne & Hélène Roche 2005. Late Pliocene homind knapping skills : the case of Lokalalei 2C, West Turkana, Kenya. Journal of Human Evolution 48, 435-472.

deHeinzelin J., J. D. Clark, T. White, W. Hart, P. Renne et al. 1999. Environment and behavior of 2.5-million-year-old Bouri hominids. Science 284, 625-629.

DeVore, Irven (Hrsg.) 1965.Primate behavior: field studies of monkeys and apes. New York: Holt, Rinehart and Winston.

Diamond, Jared M. 1982. Evolution of bowerbirds' bowers: animal origin of the aesthetic sense. Nature 297, 99-102.

Diamond, Jared M. 1987. Bower building and decoration by the bowerbird *Amblyornis inornatus*. Ethology 74, 177-204.

Domínguez-Rodrigo, Manuel, Travis Rayne Pickering, Sileshi Semaw & Michael J. Rogers 2005. Cutmarked bones from Pliocene archaeological sites at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. Journal of Human Evolution 48, 109-121.

Donald, Merlin 2001. A mind so rare. The evolution of human consciousness. New York, London: W. W. Norton & Company.

Duff, Andrew I., Geoffrey A. Clark & Thomas J. Chadderdon 1992. Symbolism in the Early Palaeolithic: a conceptual odyssey. Cambridge Archaeological Journal 2/2, 211-229.

Eaton, G. Gray 1972. Snowball construction by a feral troop of Japanese macaques (Macaca fuscata) living under seminatural conditions. Primates 13, 411-414.

Eccles, John C. 1993. Die Evolution des Gehirns – die Erschaffung des Selbst. München, Zürich: Piper.

Egg, Markus 1992. Zur Ausrüstung des Toten vom Hauslabjoch, Gem. Schnals (Südtirol). In Frank Höpfel, Werner Platzer & Konrad Spindler (Hrsg.), Der Mann im Eis Band 1. Bericht über das Internationale Symposium 1992 in Innsbruck. Veröffentlichungen der Universität Innsbruck 187. Innsbruck: Eigenverlag der Universität Innsbruck, 254-272.

Eibl-Eibesfeldt, Irenäus 1995. Die Biologie des menschlichen Verhaltens. Grundriß der Humanethologie. 3., überarb. und erw. Aufl. München, Zürich: Piper.

Einwögerer, Thomas 2000. Die jungpaläolithische Station auf dem Wachtberg in Krems, NÖ. Mitteilungen der Prähistorischen Kommission 34. Wien.

Enard, Wolfgang, Molly Przeworski, Simon E. Fisher, Cecilia S. L. Lai, Victor Wiebe, Takashi Kitano, Anthony P. Monaco & Svante Pääbo 2002. Molecuar evolution of *FOXP2*, a gene involved in speech and language. Nature 418, 869-872.

Enard, Wolfgang, Philipp Khaitovich, Joachim Klose, Sebastian Zöllner, Florian Heissig, Patrick Giavalisco, Kay Nieselt-Struwe, Elaine Muchmore, Ajit Varki, Rivka Ravid, Gaby M. Doxiadis, Ronald E. Bontrop & Svante Pääbo 2002. Intra- and interspecific variation in primate gene expression patterns. Science 296, 340-343.

Engelien, Almut 2002. Störungen des auditiven Verarbeitens. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 435-442.

Eriksen, Berit Valentin (Hrsg.) 2000. Flintstudier: en håndbog i systematiske analyser af flintinventarer. Århus : Aarhus Universitetsforlag.

Eriksen, Berit Valentin im Druck. Colourful lithics – the "chaîne opératoire" of heat treated chert artefacts in the Early Mesolithic of Southwest Germany. In Claus-Joachim Kind (Hrsg.), Proceedings of the conference "After the Ice Age", Rottenburg, September 2003.

Falk, Dean 1980. Hominid brain evolution: the approach from paleoneurology. Yearbook of Physical Anthropology 23, 93-107.

Falk, Dean 1987. Hominid palaeneurology. Annual Review of Anthropology 16, 13-30.

Falk, Dean, Charles Hildebolt, Kirk Smith, M. J. Morwood,Thomas Sutikna, Peter Brown, Jatmiko, E. Wayhu Saptomo, Barry Brunsden & Fred Prior 2005. The brain of LB1, *Homo floresiensis*. Science 308, 242-245.

Falk, Dean, John C. Redmond Jr., John Guyer, Glenn C. Conroy, Wolfgang Recheis, Gerhard W. Weber & Horst Seidler 2000. Early hominid brain evolution: a new look at old endocasts. Journal of Human Evolution 38, 695-717.

Fernandes, Marcus E.B. 1991. Tool use and predation of oysters (*Crassostrea rhizophorae*) by the Tufted Capuchin (*Cebus apella apella*) in brackish water mangrove swamp. Primates 32/4, 529-531.

Ferring, Reid, Oms, Oriol, Agustí, Jordi, Berna, Francesco, Nioradze, Medea, Shelia, Teona, Tappen, Martha, Vekua, Abesalom, Zhvania, David, and David Lordkipanidze 2011. Earliest human occupations at Dmanisi (Georgian Caucasus) dated to 1.85–1.78 Ma. PNAS 108/26, 10432-10436

Flannery, Kent V. & Joyce Marcus 1993. Cognitive archaeology. In Viewpoint: What is cognitive archaeology? Cambridge Archaeological Journal 3/2, 247-270.

Fontaine, B., P. Y. Moisson & E. J. Wickings 1995. Observations of spontaneous tool making and tool use in a captive group of western lowland gorillas (*Gorilla gorilla gorilla*). Folia Primatologica 65, 219-223.

Fossey, Diane 1989. Gorillas im Nebel. München: Kindler.

Fox, Elizabeth A. & Ibrahim bin'Muhammad 2002. New tool use by wild Sumatran orangutans (*Pongo pygmaeus abelii*). American Journal of Physical Anthropology 119, 186-188.

Fox, Elizabeth, Arnold F. Sitompul & Carel P. van Schaick 1999. Intelligent tool use in wild Sumatran orangutans. In Parker, Sue Taylor, Robert W. Mitchell & H. Lyn Miles (Hrsg.), The mentalities of gorillas and orangutans: comparative perspectives. Cambridge: Cambridge University Press, 99-116.

Gabunia, Leo, Abesalom Vekua, David Lordkipanidze, Carl C. Swisher III, Reid Ferring, Antje Justus, Medea Nioradze, Merab Tvalchrelidze, Susan C. Antón, Gerhard Bosinski, Olaf Jöris, Marie-A. de Lumley, Givi Majsuradze, Aleksander Mouskhelishvili 2000. Earliest Pleistocene hominid cranial remains from Dmanisi, Republic of Georgia: Taxonomy, geological setting, and age. Science 288, 1019-1025.

Galdikas, Biruté M. F. 1982. Orang-utan tool use at Tanjung Puting Reserve, Central Indonesian Borneo (Kalimantan Tengah). Journal of Human Evolution 10,19-33.

Galdikas, Biruté 1995. Refelections of Eden: my years with the orang-utans of Borneo. Boston: Little, Brown.

Gallup, Gordon G. Jr. 1970. Chimpanzees: self-recognition. Science 167, 86-87.

Gallup, Gordon G. Jr. 1975. Towards an operational definition of self-awareness. In Russell H. Tuttle (Hrsg.), Socioecology and psychology of primates. The Hague, Paris: Mouton, 309-341.

Gardner, Howard 1991. Abschied vom IQ. Die Rahmen-Theorie der vielfachen Intelligenzen. Stuttgart: Klett-Cotta.

Gargett, R. H. 1989. Grave shortcomings: The evidence for Neandertal burial. Current Anthropology 30, 157-190.

Gaudzinski, Sabine 1999. Middle Palaeolithic bone tools from the open-air site Salzgitter Lebenstedt (Germany). Journal of Archaeological Science 26/2, 125-141.

Geneste, Jean-Michel 1985. Analyse lithique d'industries moustériennes du Périgord: une approche technoligique du comportement des groupes humains au Paléolithique moyen. Bordeaux: Université de Bordeaux I.

Gibson, Kathleen R. 1990. New perspectives on instincts and intelligence: brain size and the emergence of hierarchical mental constructional skills. In Sue Taylor Parker & Kathleen R. Gibson (Hrsg.), 'Language' and intelligence in monkeys and apes: comparative developmental perspectives. Cambridge: Cambridge University Press, 97-128.

Gibson, Kathleen. R. 1996. The biocultural human brain, seasonal migrations, and the emergence of the Upper Paleolithic. In Paul Mellars & Kathleen R. Gibson (Hrsg.), Modelling the early human mind. Cambridge: The McDonald Institute for Archaeological Research, 33-46.

Gibson, Kathleen R. & Tim Ingold (Hrsg.) 1993. Tools, language and cognition in human evolution. Cambridge: Cambridge University Press.

Gold, Kenneth C. 2002. Ladder use and clubbing by a bonobo (*Pan paniscus*) in Apenheul Primate Park. Zoo Biology 21, 607-611.

Goldenberg, Georg 2002. Störungen des visuellen Erkennens und des bildlichen Vorstellens. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 296-315.

Goodall, Jane 1964. Tool-using and aimed throwing in a community of free-living chimpanzees. Nature 201, 1264-1266.

Goodall, Jane 1986. The chimpanzees of Gombe: Patterns of behavior. Cambridge/Mass., London: The Belknap Press of Harvard University Press.

Goren-Inbar, N., N. Alperson, M. E. Kislev, O. Simchoni, Y. Melamed, A. Ben-Nun & E. Werker 2004. Evidence of hominin control of fire at Gesher Benot Ya'akov, Israel. Science 304, 725-727.

Goren-Inbar, Naama, Ella Werker & Craig S. Feibel 2002. The Acheulian site of Gesher benot Ya'akov, Israel: 1, The wood assemblage. Oxford: Oxbow Books.

Gould, Stephen Jay & Elisabeth S. Vrba 1982. Exaptation – a missing term in the science of form. Paleobiology 8/1, 4-15.

Gowlett, J. A. 1991. Kilombe – review of an Acheulean site complex. In D. Clark (Hrsg.), Cultural beginnings. Bonn: Habelt, 129-136.

Gowlett, J. A. J. 1993. Le site Acheuléen de Kilombe: stratigraphie, geochronology, habitat et industrie lithique. L'anthropologie 97, 69-84.

Gowlett, J. A. J. 1994. Early human mental abilities. In Steve Jones, Robert Martin & David Pilbeam (Hrsg.), The Cambridge encyclopedia of human evolution, 2. Aufl., Cambridge: Cambridge University Press, 341-345.

Graves-Brown, P. M. 1995. Fearful symmetry. World Archaeology 27/1, 88-99.

Grünberg, Judith M., Heribert Graetsch, Ursula Baumer und Johann Koller 1999. Untersuchung der mittelpaläolithischen „Harzreste“ von Königsaue, Ldkr. Aschersleben-Staßfurt. Jahresschrift der mitteldeutschen Vorgeschichte 81, 7-38.

Guillaume, P. & I. Meyerson 1930. Recherches sur l’usage de l’instrument chez les singes. I. Le problème du détour. Journal de Psychologie Normale et Pathologique 27, 177-236.

Guillaume, P. & I. Meyerson 1931. Recherches sur l’usage de l’instrument chez les singes. II. L‘intermédiaire lié à l’objet. Journal de Psychologie Normale et Pathologique 28, 481-555.

Guillaume, P. & I. Meyerson 1934. Recherches sur l’usage de l’instrument chez les singes. III. L’intermédiaire indépendant de l’objet. Journal de Psychologie Normale et Pathologique 31, 496-554.

Häußer, Annemarie 1995. Mediona I (katalonien). Zusammensetzungen der Steinartefakte – eine Methode zur Überprüfung der Stratigraphie. Unpubl. Magisterarbeit, Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, Universität Tübingen.

Hahn, Joachim 1993. Erkennen und Bestimmen von Stein- und Knochenartefakten. Einführung in die Artefaktmorphologie. 2. Aufl. Tübingen: Archaeologica Venatoria.

Haidle, Miriam Noël 1999. Der Unterschied liegt in der Zukunft: Untersuchungen zur Planungstiefe als Marker kognitiver Evolution. Mitteilungen der Anthropologischen Gesellschaft in Wien 129, 1-11.

Haidle, Miriam Noël 2000. Neanderthals – ignorant relatives or thinking siblings? A discussion of the „cognitive revolution“ at around 40,000 B.P. In Jörg Orschiedt & Gerd-Christian Weniger (Hrsg.), Neanderthals and modern humans – discussing the transition: Central and Eastern Europe from 50,000 – 30,000 B.P. Mettmann: Neanderthal-Museum, 275-286.

Haidle, Miriam Noël 2003. Eiszeitschmuck – Schönheit, Selbstbewusstsein und Kommunikation. In Stefanie Kölbl & Nicholas J. Conard (Hrsg.), Eiszeitschmuck. Status und Schönheit. Museumsheft 6. Blaubeuren: Urgeschichtliches Museum Blaubeuren, 9-14.

Haidle, Miriam Noël 2004a. Menschenaffen? Affenmenschen? Menschen! Kognition und Sprache im Altpaläolithikum. In Nicholas J. Conard (Hrsg.), Woher kommt der Mensch? Tübingen: Attempto, 69-97.

Haidle, Miriam Noël 2004b. Skilful, but apish or on the way to becoming human? Object planning in the Lower Palaeolithic. In: Toussaint, M., C. Draily und J.-M. Cordy (Hrsg.), Section 4: Premiers Hommes et Paléolithique Inférieur, Sessions générales et posters. Actes du XIVème Congrès UISPP, Université de Liège, Belgique, 2-8 septembre 2001, BAR Int. Series 1272, 69-73.

Hall, K. R. L. & George B. Schaller 1964. Tool-using behavior of the California sea otter. Journal of Mammalogy 45/2, 287-298.

Hallos, J. 2005. “15 minutes of fame”: exploring the temporal dimension of Middle Pleistocene lithic technology. Journal of Human Evolution 49, 155-179.

Harris, J. W. K. & G. Isaac 1976. The Karari industry: early Pleistocene archaeological evidence from the terrain east of Lake Turkana, Kenya. Nature 262, 102-107.

Harris, J. W. K., P.G. Williamson, J. Verniers, M. J. Tappen, K. Stewart, D. Helgren, J. de Heinzelin, N. T. Boaz & R. V. Bellomo 1987. Late Pliocene hominid occupation in Central Africa: the setting, context, and character of the Senga 5 A site, Zaire. Journal of Human Evolution 16, 701-728.

Hart, Benjamin L., Lynette A. Hart, Michael McCoy & C. R. Sarath 2001. Cognitive behaviour in Asian elephants: use and modification of branches for fly switching. Animal Behaviour 62, 839-847.

Hartje, Wolfgang 2002. Funktionelle Asymmetrie der Großhirnhemisphären. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 67-92.

Heise, Kathy, Lance G. Barrett-Lennard, Eva Saulitis, Craig Matkin & David Bain 2003. Examining the evidence for killer whale predating on Steller sea lions in British Columbia and Alaska. Aquatic Mammals 29/3, 325-334.

Henry-Gambier, Dominique, Bruno Maureille & Randall White 2004. Vestiges humains des niveaux de l'Aurignacien ancien du site de Brassempouy (Landes). Bulletins et Mémoires de la Société d'Anthropologie de Paris n.s. 16/1-2, 49-87.

Henshilwood, Christopher S., Francesco d'Errico, Curtis W. Marean, Richard G. Milo & Royden Yates 2001. An early bone tool industry from the Middle Stone Age at Blombos Cave, South Africa: implications for the origins of modern human behaviour, symbolism and language. Journal of Human Evolution 41, 631-678.

Henshilwood, Christopher S., Francesco d'Errico, Royden Yates, Zenobia Jacobs, Chantal Tribolo, Geoff A. T. Duller, Norbert Mercier, Judith C. Sealy, Helene Valladas, Ian Watts & Ann G. Wintle 2002. Emergence of modern human behavior: Middle Stone Age engravings from South Africa. Science 295, 1278-1280.

Henshilwood, Christopher, Francesco d'Errico, Marian Vanhaeren, Karen van Niekerk & Zenobia Jacobs 2004. Middle Stone Age shell beads from South Africa. Science 304, 404.

Henshilwood, Christopher S. & Curtis W. Marean 2003. The origin of modern behavior. Critique of the models and their test implications. Current Anthropology 44/5, 627-651.

Henty, C. J. 1986. Development of snail-smashing by Song Thrushes. British Birds 79, 277 281.

Heyes, C. M. 1994. Reflections on self-recognition in primates. Animal Behaviour 47, 909 919.

Hicks, Thurston C., Roger S. Fouts & Deborah H. Fouts 2005. Chimpanzee (*Pan troglodytes troglodytes*) tool use in the Ngotto Forest, Central African Republic. American Journal of Primatology 65, 221-237.

Hill, Andrew, Steven Ward, Alan Deino, Garniss Curtis & Robert Drake 1992. Earliest *Homo*. Nature 355, 719-722.

Hirschberg, Walter & Alfred Janata 1986^3. Technologie und Ergologie in der Völkerkunde Band 1. Berlin: Dietrich Reimer.

Hodder, Ian 1993. Social cognition. In Viewpoint: What is cognitive archaeology? Cambridge Archaeological Journal 3/2, 247-270.

Hohmann, Gottfried & Barbara Fruth 2003. Culture in bonobos? Between-species and within species variation in behavior. Current Anthropology 44/4, 563-571.

Holdaway, Simon 1996. Tool hafting with mastic. Nature 380, 288-289.

Holdermann, Claus-Stephan, Hansjürgen Müller-Beck & Ulrich Simon (Hrsg.) 2001. Eiszeitkunst im süddeutsch-schweizerischen Jura: Anfänge der Kunst. Stuttgart: Theiss.

Holloway, Ralph 1969. Culture – a human domain. Current Anthropology 10, 395-412.

Holloway, Ralph 1972. Australopithecine endocasts, brain evolution in the Hominoidea, and a model of hominid evolution. In Russell Tuttle (Hrsg.), The functional and evolutionary biology of primates. Chicago, New York: Aldine-Atherton, 185-203.

Hoppe, Ralf 2005. Die Weltbürste. Der Spiegel 26/2005, 108-113.

Horner, V. & A. Whiten 2005. A causal knowledge and imitation/emulation swithing in chimpanzees (Pan troglodytes) and children. Animal Cognition 8, 164-181.

Hou Yamei, Richard Potts, Yuan Baoyin, Guo Zhentang, Alan Deino, Wang Wie, Jennifer Clark, Xie Guangmao & Huang Weiwen 2000. Mid Pleistocene Acheulean-like stone technology of the Bose Basin, South China. Science 287, 1622-1626.

Howell, F.C. 1955, A preliminary note on a prehistoric donga (Mac Lennan's Donga) in Central Tanganyika. South African Archaeological Bulletin 10, 43-52.

Howell, F. Clark, Glen H. Cole & Maxine Kleindienst 1962. Isimila, an Acheulian occupation site in the Iringa Highlands, Southern Highlands Province, Tanganyika. Actes du Congrès Panafricain de la Préhistoire et d' Etudes Quaternaires 4/1959, 43-83.

Howell, F. C., P. Haesaerts & J. deHeinzelin 1987. Depositional environments, archaeological occurrences and hominid from Members E and F of the Shungura Formation (Omo basin, Ethiopia). Journal of Human Evolution 16, 665-700.

Huber, Walter, Klaus Poeck & Dorothea Weniger 2002. Aphasie. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 93-160.

Huffman, Michael A. 1984. Stone-play of *Macaca fuscata* in Arashiyama B troop: transmission of a non-adaptive behavior. Journal of Human Evolution 13/8, 725-735.

Huffman, Michael A. & Duane Quiatt 1986. Stone handling by Japanese Macaques (*Macaca fuscata*): implications for tool use of stone. Primates 27/4, 413-423.

Hunt, Gavin R. 1996. Manufacture and use of hook-tools by New Caledonian crows. Nature 379, 249-251.

Hunt, Gavin R. 2000a. Human-like, population-level specialization in the manufacture of pandanus tools by New Caledonian crows *Corvus moneduloides*. Proceedings of the Royal Society of London B 267, 403-413.

Hunt, Gavin R. 2000b. Tool use by the New Caledonian crow *Corvus moneduloides* to obtain Cerambycidae from dead wood. Emu 100, 109-114.

Hunt, Gavin R. & Russell D. Gray 2002. Species-wide manufacture of stick-type tools by New Caledonian crows. Emu 102, 349-353.

Hunt, Gavin R. & Russell D. Gray 2003. Diversification and cumulative evolution in New Caledonian crow tool manufacture. Proceedings of the Royal Society of London B 270, 867-874.

Hunt, Gavin R. & Russell D. Gray 2004. The crafting of hook tools by wild New Caledonian crows. Proceedings of the Royal Society of London B 271, S88-S90.

Ingmanson, Ellen J. 1996. Tool-using behavior in wild *Pan paniscus*: Social and ecological considerations. In Russon, Anne E., Kim A. Bard & Sue Taylor Parker (Hrsg.), Reaching into thought. The minds of the great apes. Cambridge: Cambridge University Press, 190-210.

Inizan, Marie-Louise, Hélène Roche & Jaques Tixier 1992. Préhistoire de la pierre taillée. Tome 3, Technology of knapped stone. Meudon: CREP.

Irrgang, Bernhard 2001. Lehrbuch der Evolutionären Erkenntnistheorie. 2., vollst. überarb. Aufl. München, Basel: E. Reinhardt.

Isaac, Glyn 1977. Olorgesailie: Archaeological Studies of a Middle Pleistocene Lake Basin on Kenya. Chicago, London: University of Chicago Press.

Issac, G. L. & J. W. K. Harris 1978. Archaeology. In M. G. Leakey & R. E. Leakey (Hrsg.), Koobi Fora research project, vol. 1. The fossil hominids and an introduction to their context. Oxford: Clarendon Press, 64-85.

Ipña, Santiago L. & Ana I. Durand 2001. Sexual dimorphism in Middle Pleistocene humans. Anthropologie 39/2-3, 99-101.

Jaspers, Karl 1997. Die Unabhängigkeit des philosophierenden Menschen. München: dtv.

Jeffreys, M.D.W. 1965. The hand bolt. MAN 147/148, 153-154.

Jones, Clyde & Jorge Sabater Pi 1969. Sticks used by chimpanzees in Rio Muni, West Africa. Nature 223, 100-101.

Jones, Peter D. 1980. Experimental butchery with modern stone tools and its relevance for palaeolithic archaeology. World Archaeology 12, 153-165.

Jordan, Claudia 1982. Object manipulation and tool-use in captive pygmy chimpanzees (*Pan paniscus*). Journal of Human Evolution 11, 35-39.

Joulian, Frédéric 1996. Comparing chimpanzee and early hominid techniques: Some contributions to cultural and cognitive questions. In Paul Mellars & Kathleen Gibson (Hrsg.), Modelling the early human mind. Cambridge: McDonald Institute for Archaeological Research, 173-189.

Joulian, Frédéric 1997. Hominzation and apes. An unnatural kinship. Diogenes 45/4, Nr. 180, 73-96.

Joulian, Frédéric 1998. Culture et intelligence technique chez les hominoïdes. Pour la Science 254, Dezember 1998, 66-72.

Joulian, Frédéric 2000. Techniques du corps et traditions chimpanzières. Terrain 34, März 2000, 37-54.

Karlin C., Bodu P. und Pélégrin J. 1991. Processus techniques et chaines opératoires. Comment les préhistoriens s'approprient un concept élaboré par les ethnologues. In H. Balfet (Hrsg.), Observer l'action technique des chaines opératoires, pour quoi faire? Paris: CNRS, 101-117.

Karlin, C. & M. Julien 1994. Prehistoric technology: A cognitive science? In Colin Renfrew & Ezra B. W. Zubrow (Hrsg.), The ancient mind. Elements of cognitive archaeology. Cambridge: Cambridge University Press, 152-164.

Kano, Takayoshi 1982. The use of leafy twigs for rain cover by pygmy chimpanzees of Wamba. Primates 23/3, 453-457.

Kano, Takayoshi 1992. The last ape. Pygmy chimpanzee behavior and ecology. Stanford: Stanford University Press.

Karnath, Hans-Otto & Walter Sturm 2002. Störungen von Planungs- und Kontrollfunktionen. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 393-411.

Kaufulu, Zefe M. & Nicola Stern 1987. The first stone artefacts to be found *in situ* within the Plio-Pleistocene Chiwondo Beds in northern Malawi. Journal of Human Evolution 16, 729-740.

Keeley, L. 1980. Experimental determination of stone tool uses. A microwear analysis. Chicago: University of Chicago Press, Prehistoric Archaeology and Ecology Series.

Kelley, Jay 2004. Neanderthal teeth lined up. Nature 428, 904-905.

Kenward, Ben, Alex A. S. Weir, Christian Rutz & Alex Kacelnik 2005. Tool manufacture by naive juvenile crows. Nature 433, 121.

Kerkhoff, Georg 2002. Störungen der visuellen Raumwahrnehmung und Raumkognition. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 316-333.

Kibunjia, Mzalendo 1994. Pliocene archaeological occurrences in the Lake Turkana basin. Journal of Human Evolution 27, 159-171.

Kibunja, M., H. Roche, F. H. Brown & R. E. Leakey 1992. Pliocene and Pleistocene archaeological sites west of Lake Turkana, Kenya. Journal of Human Evolution 23, 431-438.

Kimbel, W. H., R. C. Walter, D. C. Johanson, K. E. Reed, J. L. Aronson, Z. Assefa, C. W. Marean, G.G. Eck, R. Bobe, E. Hovers, Y. Rak, C. Vondra, T. Yemane, D. York, Y. Chen, N. M. Evensen & P. E. Smith 1996. Late Pliocene *Homo* and Oldowan tools from the Hadar Formation (Kada Hadar Member), Ethiopia. Journal of Human Evolution 31/6, 549-561.

Kimura, Yuki 1999. Tool-using strategies by early hominids at Bed II, Olduvai Gorge, Tanzania. Journal of Human Evolution 37, 807-831.

Kimura, Yuki 2002. Examining time trends in the Oldowan technology at Beds I and II, Olduvai Gorge. Journal of Human Evolution 43, 291-321.

Kitahara-Frisch, Jean 1977. Tools or toys? Journal of the Anthropological Society of Nippon 85/1, 57-64.

Kitahara-Frisch, Jean 1993. The origin of secondary tools. In A. Berthelet & J. Chavaillon (Hrsg.), The use of tools by human and non-human primates. A Fyssen Foundation Symposium. Oxford: Clarendon Press, 239-246.

Kitahara-Frisch, Jean, K. Norikoshi & K. Hara 1987. Use of a bone fragment as a step towards secondary tool use in captive chimpanzee. Primate Report 18, 33-37.

Kano, Takayoshi 1982. The use of leafy twigs for rain cover by pygmy chimpanzees of Wamba. Primates 23/3, 453-457.

Kano, Takayoshi 1992. The last ape. Pygmy chimpanzee behavior and ecology. Stanford: Stanford University Press.

Karnath, Hans-Otto & Walter Sturm 2002. Störungen von Planungs- und Kontrollfunktionen. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 393-411.

Kaufulu, Zefe M. & Nicola Stern 1987. The first stone artefacts to be found *in situ* within the Plio-Pleistocene Chiwondo Beds in northern Malawi. Journal of Human Evolution 16, 729-740.

Keeley, L. 1980. Experimental determination of stone tool uses. A microwear analysis. Chicago: University of Chicago Press, Prehistoric Archaeology and Ecology Series.

Kelley, Jay 2004. Neanderthal teeth lined up. Nature 428, 904-905.

Kenward, Ben, Alex A. S. Weir, Christian Rutz & Alex Kacelnik 2005. Tool manufacture by naive juvenile crows. Nature 433, 121.

Kerkhoff, Georg 2002. Störungen der visuellen Raumwahrnehmung und Raumkognition. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 316-333.

Kibunjia, Mzalendo 1994. Pliocene archaeological occurrences in the Lake Turkana basin. Journal of Human Evolution 27, 159-171.

Kibunja, M., H. Roche, F. H. Brown & R. E. Leakey 1992. Pliocene and Pleistocene archaeological sites west of Lake Turkana, Kenya. Journal of Human Evolution 23, 431-438.

Kimbel, W. H., R. C. Walter, D. C. Johanson, K. E. Reed, J. L. Aronson, Z. Assefa, C. W. Marean, G.G. Eck, R. Bobe, E. Hovers, Y. Rak, C. Vondra, T. Yemane, D. York, Y. Chen, N. M. Evensen & P. E. Smith 1996. Late Pliocene *Homo* and Oldowan tools from the Hadar Formation (Kada Hadar Member), Ethiopia. Journal of Human Evolution 31/6, 549-561.

Kimura, Yuki 1999. Tool-using strategies by early hominids at Bed II, Olduvai Gorge, Tanzania. Journal of Human Evolution 37, 807-831.

Kimura, Yuki 2002. Examining time trends in the Oldowan technology at Beds I and II, Olduvai Gorge. Journal of Human Evolution 43, 291-321.

Kitahara-Frisch, Jean 1977. Tools or toys? Journal of the Anthropological Society of Nippon 85/1, 57-64.

Kitahara-Frisch, Jean 1993. The origin of secondary tools. In A. Berthelet & J. Chavaillon (Hrsg.), The use of tools by human and non-human primates. A Fyssen Foundation Symposium. Oxford: Clarendon Press, 239-246.

Kitahara-Frisch, Jean, K. Norikoshi & K. Hara 1987. Use of a bone fragment as a step towards secondary tool use in captive chimpanzee. Primate Report 18, 33-37.

Klein, Richard G. 1978. The fauna and overall interpretation of the "Cutting 10" Acheulean site at Elandsfontein (Hopefield), Southwestern Cape Province, South Africa. Quarternary Research 10, 69-83.

Klein, Richard G. 1995. Anatomy, behavior, and modern human origins. Journal of World Prehistory 9/2, 167-198.

Klein, Richard G. 2000. Archaeology and the evolution of human behavior. Evolutionary Anthropology 9, 17-36.

Klein, Richard & Blake Edgar 2002. The dawn of human culture. New York: John Wiley & Sons.

Kleindienst, M.R. & C. M. Keller 1976. Towards a functional analysis of handaxes and cleavers: the evidence from Eastern Africa. MAN (N.S) 11, 176-187.

Klíma, Bohuslav 1983. Dolní Věstonice –tábořiště lovců mamutů. Prag: Academia nakladatelství Československé akademie věd.

Klíma, Bohuslav 1991. Die jungpaläolithischen Mammutjägersiedlungen Dolní Věstonice und Pavlov in Südmähren – ČSFR. Archäologie und Museum 23, Berichte aus der Arbeit des Amtes für Museen und Archäologie des Kantons Baselland. Liestal/Schweiz.

Köhler, Wolfgang 1963. Intelligenzprüfungen an Menschenaffen. Unveränderter Nachdruck der 2., durchges. Aufl. der „Intelligenzprüfungen an Anthropoiden I", Abhandlungen der Preussischen Akademie der Wissenschaften Jahrgang 1917, Physikal.-Mathem. Klasse 1, 1921 Berlin: Springer.

Kohn, Marek & Steven Mithen 1999. Handaxes: products of sexual selection? Antiquity 73, 518-526.

Koller, Johann, Ursula Baumer & Dietrich Mania 2001. High-tech in the Middle Palaeolithic: Neanderthal-manufactured pitch identified. European Journal of Archaeology 4/3, 385-397.

Kortlandt, Adriaan 1967. Reply to S. L. Washburn and Phyllis C. Jay: More on tool-use among primates. Current Anthropology 8/3, 255-257.

Kortlandt, Adriaan 1986. The use of stone tools by wild-living chimpanzees and earliest hominids. Journal of Human Evolution 15/2, 77-132.

Krützen, Michael, Janet Mann, Michael R. Heithaus, Richard C. Connor, Lars Bejder & William B. Sherwin 2005. Cultural transmission of tool use in bottlenose dolphins. Proceedings of the National Academy of Science 102/25, 8939-8943.

Kuman, Kathleen 1994. The archaeology of Sterkfontein – past and present. Journal of Human Evolution 27, 471-495.

Kuman, Kathleen 2003. Site formation in the early South African Stone Age sites and its influence on the archaeological record. South African Journal of Science 99, 251-254.

Kummer, H. & Jane Goodall 1985. Conditions of innovative behaviour in primates. Philosophical Transactions of the Royal Society London, B308, 203-214.

Lai, Cecilia S. L., Simon E. Fisher, Jane A. Hurst, Faraneh Vargha-Khadem & Anthony P. Monaco 2001. A forkhead-domain gene is mutated in a severe speech and language disorder. Nature 413, 519-523.

Lancaster, Jane B. 1968. On the evolution of tool-using behavoir. American Anthropologist 70, 58-66.

Lanjouw, Annette 2002. Behavioural adaptation to water scarcity in Tongo chimpanzees. In Christophe Boesch, Gottfried Hohmann & Linda F. Marchant (Hrsg.), Behavioural diversity in chimpanzees and bonobos. Cambridge: Cambridge University Press, 52-60

Leakey, Louis S. B. 1965. Olduvai Gorge 1951-61 Vol. I: A preliminary report on the geology and fauna. Cambridge: Cambridge University Press.

Leakey, Mary D. 1971. Olduvai Gorge Vol. III: Excavations in Beds I and II, 1960-1963. Cambridge: Cambridge University Press.

Leakey, Meave G., Fred Spoor, Frank H. Brown, Patrick N. Gathogo, Christopher Kiarie, Louise N. Leakey & Ian McDougall 2001. New hominin genus from eastern Africa shows diverse middle Pleistocene lineages. Nature 410, 433-440.

Lefebvre, Louis, Nektaria Nicolakakis & Denis Boire 2002. Tools and brains in birds. Behaviour 139, 939-973.

Lemonnier, Pierre 1983. La description des systèmes techniques: Une urgence en technologie culturelle. Techniques et Culture 1, 11-26.

Lemonnier, Pierre 1986. The study of material culture today: Toward an anthropology of technical systems. Journal of Anthropological Archaeology 5, 147-186.

Lemonnier, Pierre 1990.Topsy turvy techniques. Remarks on the social representation of techniques. Archaeological Review from Cambridge 9/1, 27-37.

Leone, Mark P. 1982. Some opinions about recovering mind. American Antiquity 47/4, 742-760.

Leroi-Gourhan, André 1964. La geste et la parole. Paris: Albin Michel.

Leroi-Gourhan, André 1984. Hand und Wort. Die Evolution von Technik, Sprache und Kunst. 3. Aufl. Frankfurt/M.: Suhrkamp.

Lethmate, Jürgen 1991. Haben Schimpansen eine materielle Kultur? Biologie in unserer Zeit 21/3, 132-139.

Lethmate, Jürgen 1994. Die Besonderheiten des Menschen. In U. Opolka (Hrsg.), Der Mensch in seiner Welt: Anthropologie heute. Bd.1: W. Schiefenhövel (Hrsg.), Vom Affen zum Halbgott: Der Weg des Menschen aus der Natur. Stuttgart, 13-41.

Leutenegger, Walter 1973. Encephalization in australopithecines : a new estimate. Folia primatologica 19, 9-17.

Lieberman, Daniel E., Brandeis M. McBratney & Gail Krovitz 2002. The evolution and development of cranial form in Homo sapiens. Proceedings of the National Academy of Science 99/3, 1134-1139.

Lieberman, Philip 1975. On the origins of language. New York: MacMillan.

Lieberman, Philip 1994². Human speech and language. In Steve Jones, Robert Martin & David Pilbeam (Hrsg.), The Cambridge encyclopedia of human evolution. Cambridge: Cambridge University Press, 134-137.

Lombard, Marlize 2005. Evidence of hunting and hafting during the Middle Stone Age at Sibudu Cava, KwaZulu-Natal, South Africa: a multianalytical approach. Journal of Human Evolution 48, 279-300.

Lorblanchet, Michel 1999. La naissance de l'art. Genèse de l'art préhistorique. Paris: Éditions Errance.

Lorenz, Konrad 1973. Die Rückseite des Spiegels. München: Piper.

Löw, Reinhard 1983. Evolution und Erkenntnis – Tragweite und Grenzen der evolutionären Erkenntnistheorie in philosophischer Absicht. In Konrad Lorenz & Franz M. Wuketits (Hrsg.), Die Evolution des Denkens. München: Piper, 331-360.

Lumley, Henri de (Hrsg.) 1969. Une cabane acheuléenne dans la grotte du Lazaret. Mémoires de la Société Préhistorique Française 7.

Mania, Dieter 1983. Autochthone Lagerplatzstrukturen im altpaläolithischen Fundhorizont auf der Steinrinne bei Bilzingsleben. Ethnographisch-Archäologische Zeitschrift 24, 296-303.

Mania, Dieter & Ursula Mania 1988. Deliberate engravings on bone artefacts of Homo erectus. Rock Art Research 5, 91-109.

Mania, Dieter & Ursula Mania 1998. Geräte aus Holz von der altpaläolithischen Fundstelle bei Bilzingsleben. Praehistorica Thuringica 2, 32-72.

Mania, Dieter & Ursula Mania 1999. Zur Kultur des Homo erectus von Bilzingsleben. Praehistoria Thuringica 3, 27-63.

Mania, Dietrich & V. Toepfer. 1973. Königsaue. Gliederung, Ökologie und mittelpaläolithische Funde der letzten Eiszeit. Veröffentlichungen des Landesmuseums für Vorgeschichte in Halle Bd. 26. Berlin: VEB Deutscher Verlag der Wissenschaften.

Marshack, Alexander 1997. The Berekhat Ram figurine: A late Acheulian carving from the Middle East. Antiquity 71, 327-337.

Martin, Robert D. 1981. Relative brain size and basal metabolic rate in terrestrial vertebrates. Nature 293, 57-60.

Mason, Betsy 2005. More animals join the learning circle. New Scientist 2514 (27.8.05), 8.

Matsusaka, Takahisa, Hitonaru Nishie, Masaki Shimada, Nobuyuki Kutsukake, Koichiro Zamma, Michio Nakamura & Toshisada Nishida 2005. Tool-use for drinking water by immature chimpanzees of Mahale: prevalence of an unessential behavior. Primates DOI: 10.1007/s10329-005-0158-4.

Matsuzawa, Tetsuro 1996. Chimpanzee intelligence in nature and in captivity: isomorphism in symbol use and tool use. In William C. McGrew, Linda F. Marchant & Toshisada Nishida (Hrsg.), Great ape societies. Cambridge, Cambridge University Press, 196-209.

Matsuzawa, Tetsuro (Hrsg.) 2001. Primate origins of human cognition and behavior. Tokyo: Springer.

Matsuzawa, Tetsuro, Dora Biro, Tatyana Humle, Noriko Inoue-Nakamura, Rikako Tonooka & Gen Yamakoshi 2001. Emergence of culture in wild chimpanzees: Education by master-apprenticeship. In Tetsuro Matsuzawa (Hrsg.), Primate origins of human cognition and behavior. Tokyo: Springer, 557-574.

McBrearty, Sally & Allison S. Brooks 2000. The revolution that wasn't: a new interpretation of the origin of modern human behavior. Journal of Human Evolution 39, 453-563.

McGrew, William C. 1974. Tool use by wild chimpanzees in feeding upon driver ants. Journal of Human Evolution 3/6, 501-508.

McGrew, William C. 1991. Chimpanzee material culture: what are the limits and why? In R. A. Foley (Hrsg.), The origins of human behaviour. London, Boston, Sydney, Wellington: Unwin Hyman, 13-24.

McGrew, William C. 1992. Chimpanzee material culture. Implications for human evolution. Cambridge: Cambridge University Press.

McHenry, Henry M. & Katherine Coffing 2000. *Australopithecus* to *Homo*: Transformations in body and mind. Annual Review of Anthropology 29, 125-146.

McPherron, Shannon Patrick 2000. Handaxes as a measure of the mental capabilities of early hominids. Journal of Archaeological Science 27, 655-663.

McPherron, Shannon Patrick 2003. Technological and typological variability in the bifaces from Tabun Cave, Israel. In Marie Soressi & H. Dibble (Hrsg.), Multiple approaches to the tudy of bifacial technologies. Philadelphia: University of Pennsylvania Museum Press, 55-76.

Mellars, Paul (Hrsg.) 1990. The emergence of modern humans: An archaeological perspective. Edinburgh: Edinburgh University Press.

Mellars, Paul 1991. Cognitive changes and the emergence of modern humans in Europe. Cambridge Archaeological Journal 1/1, 63-76.

Mellars, Paul 1996. Symbolism, language, and the Neanderthal mind. In Paul Mellars & Kathleen R. Gibson (Hrsg.), Modelling the early human mind. Cambridge: The McDonald Institute for Archaeological Research, 15-32.

Mellars, Paul 2005. The impossible coincidence. A single-species model for the origins of modern human behavior in Europe. Evolutionary Anthropology 14, 12-27.

Mellars, Paul & Kathleen R. Gibson (Hrsg.) 1996. Modelling the early human mind. Cambridge: The McDonald Institute for Archaeological Research.

Mellars, Paul & Chris Stringer (Hrsg.) 1989. The human revolution: Behavioural and biological perspectives on the origins of modern humans. Princeton: Princeton University Press.

Mercader, Julio, Melissa Panger & Christophe Boesch 2002. Excavation of a chimpanzee stone tool site in the African rainforest. Science 296, 1452-1455.

Mithen, Steven S. 1994. From domain specific to generalized intelligence: a cognitive interpretation of the Middle/Upper Palaeolithic transition. In Colin Renfrew & Ezra B.W. Zubrow (Hrsg.), The ancient mind: elements of cognitive archaeology. Cambridge: Cambridge University Press, 29-39.

Mithen, Steven 1996. The prehistory of the mind. A search for the origins of art, religion and science. London: Thames and Hudson.

Moggi-Cecchi, Jacopo 2001. Questions of growth. Nature 414, 595-597.

Monigal, Katherine 2002. The Levantine Leptolithic. Blade production from thbe Lower Paleolithic to the dawn of the Upper Paleolithic. Unpubl. Dissertation Southern Methodist University, Dallas, Texas.

Mora, Rafael & Ignacio de la Torre 2005. Percussion tools in Olduvai Bed I and II (Tanzania): implications for early human activities. Journal of Anthropological Archaeology 24, 179-192.

Morwood, M. J., R. P. Soejono, R. G. Roberts, T. Sutikna, C. S. M. Turney, K. E. Westaway, W. J. Rink, J.-X. Zhao, G. D. van den Bergh, Rokus Awe Due, D. R.Hobbs, M. W.

Moore, M. I. Bird & L. K. Fifield 2004. Archaeology and age of a new hominin from Flores in eastern Indonesia. Nature 431, 1087-1091.

Movius, Hallam L. 1949. The Lower Palaeolithic cultures of Southern and Eastern Asia. Transactions of the American Philosophical Society NS 38/4, 1948, 330-420.

Müller-Karpe, Hermann 2001a. Geschichtliche Bedeutung der paläolithischen Religion. Bayerische Vorgeschichtsblätter 66, 1-5.

Müller-Karpe, Hermann 2001b. Überlegungen zum Beginn der Menschheitsgeschichte. Historische Zeitschrift 273, 281-288.

Müller-Karpe, Hermann 2001c. Zum Beginn von Geistes- und Religionsgeschichte. Germania 79, 223-235.

Müller-Karpe, Herrmann, Karl Dietrich Adam, Thomas Bargatzky, Reinhard Bernbeck, Peter F. Biehl, Henri J. M. Claessen, Christoph Elsas, Lutz Fiedler, Miriam Noël Haidle, Svend Hansen, Winfried Henke, Joachim Herrmann, Christoph Huth, Heribert Illig, Rolf Löther, Hans Mohr, Felix Müller, Hansjürgen Müller-Beck, Heinz Jürgen Niedenzu, Thomas Terberger & Helmut Ziegert 2005. Geschichtlichkeit des paläolithischen Menschen. Fakten und Anschauungen. Erwägen Wissen Ethik 16/1, 85-146.

Nakamichi, Masayuki 1998. Stick throwing by gorillas (*Gorilla gorilla gorilla*) at the San Diego Wild Animal Park. Folia Primatologica 69, 291-295.

Nakamichi, Masayuki 1999. Spontaneous use of sticks as tools by captive gorillas. Primates 40, 487-498.

Natale, Francesco, Patrizia Poti’ & Giovanna Spinozzi 1988. Development of tool use in a macaque and a gorilla. Primates 29/3, 413-416.

Nelson, M. 1991. The study of technological organization. In M. B. Schiffer (Hrsg.), Archaeological Method and Theory 3, Tucson: University of Arizona Press, 57-100.

Newcomer, M.H. 1971. Some quantitative experiments in handaxe manufacture. World Archaeology 3/1, 85-94.

Nielsen, M., E. Collier-Baker, J. M. Davis & T. Suddendorf 2005. Imitation recognition in a captive chimpanzee (*Pan troglodytes*). Animal Cognition 8, 31-36.

Nishida, Toshisada 1973. The ant-gathering behaviour by the use of tools among wild chimpanzees of the Mahali Mountains. Journal of Human Evolution 2, 357-370.

Nishida, Toshisada & Mariko Hiraiwa 1982. Natural history of a tool-using behavior by wild chimpanzees in feeding upon wood-boring ants. Journal of Human Evolution 11/1, 73-99.

Nishimura, Takeshi, Naobi Okayasu, Yuzuru Hamada & Juichi Yamagiwa 2003. A case report of a novel type of stick use by wild chimpanzees. Primates 44, 199-201.

Noble, William & Iain Davidson 1991. The evolutionary emergence of modern human behaviour: language and its archaeology. Man N.S. 26, 233-253.

Noble, William & Iain Davidson 1993. Tracing the emergence of modern human behavior: Methodological pitfalls and a theoretical path. Journal of Anthropological Archaeology 12, 121-149.

Noble, William & Iain Davidson 1996. Human evolution, language and mind. A psychological and archaeological inquiry. Cambridge: Cambridge University Press.

Oakley, Kenneth P. 1963. Man the tool-maker. 5.Aufl. London: British Museum.

Oakley, Kenneth P., P. Andrews, L. H. Keeley & J. D. Clark 1977. A reappraisal of the Clacton spearpoint. Proceedings of the Prehistoric Society 43, 13-30.

O'Brien, Eileen 1981. The projectile capabilities of an Acheulian handaxe from Olorgesaillie. Current Anthropology 22/1, 76-79.

O'Brien, Eileen 1985. What was the Acheulean hand axe? Natural History 7, 21-23.

O'Connell, J. F., K. Hawkes & N. G. Blurton Jones 1999. Grandmothering and the evolution of *Homo erectus*. Journal of Human Evolution 36, 461-485.

O'Malley, Robert C. & W. C. McGrew 2000. Oral tool use by captive orangutans (*Pongo pygmaeus*). Folia primatologica 71, 334-341.

Olive, Monique 1988. Une habitation magdalénienne d'etiolles : l'unité P.15. Mémoires de la Société préhistorique française 20. Châlons-sur-Marne: Paquez.

Orschiedt, Jörg & Gerd-Christian Weniger (Hrsg.) 2000. Neanderthals and modern humans – discussing the transition: Central and Eastern Europe from 50,000 – 30,000 B.P. Mettmann: Neanderthal-Museum.

Osvath, Mathias & Peter Gärdenfors 2005. Oldowan culture and the evolution of anticipatory cognition. Lund: Lund University Cognitive Studies 122.

Otte, Marcel 2001. Les origines de la pensée. Archéologie de la conscience. Sprimont: Mardaga.

Ottoni, Eduardo B. & Massimo Mannu 2001. Semifree-ranging tufted capuchins (*Cebus apella*) spontaneously use tools to crack open nuts. International Journal of Primatology 22/3, 348-358.

Paddayya, K. 1977. An Acheulian occupation site at Hunsgi, Peninsular India: a summary of the results of two seasons of excavation (1975-6). World Archaeology 8/3, 342-355.

Parker, Sue Taylor & Kathleen R. Gibson 1977. Object manipulation, tool use and sensorimotor intelligence as feeding adaptations in Cebus monkeys and great apes. Journal of Human Evolution 6, 623-641.

Parker, Sue Taylor & Kathleen R. Gibson (Hrsg.) 1990. 'Language' and intelligence in monkeys and apes: comparative developmental perspectives. Cambridge: Cambridge University Press.

Parker, Sue Taylor, Mary Kerr, Hal Markowitz & Jay Gould 1999. A survey of tool use in zoo gorillas. In Parker, Sue Taylor, Robert W. Mitchell & H. Lyn Miles (Hrsg.), The mentalities of gorillas and orangutans: comparative perspectives. Cambridge: Cambridge University Press, 188-195.

Parker, Sue Taylor & Constance Milbrath 1993. Higher intelligence, propositional language, and culture as adaptations for planning. In Kathleen R. Gibson & Tim Ingold (Hrsg.), Tools, language and cognition in human evolution. Cambridge: Cambridge University Press, 314-333.

Parkington, J. 1990. A critique of the consensus view on the age of Howieson's Poort assemblages in South Africa. In Paul Mellars (Hrsg.), The emergence of modern humans: An archaeological perspective. Edinburgh: Edinburgh University Press, 34-55.

Parnell, Richard J. & Hannah M. Buchanan-Smith 2001. Animal behaviour: An unusual social display by gorillas. Nature 412, 294.

Paul, Andreas 1998. Von Affen und Menschen. Verhaltensbiologie der Primaten. Darmstadt: Wissenschaftliche Buchgesellschaft.

Pawlik, Alfred F. 2002a. Acheulean in Nueva Ecija? a report from the 2001 ASP Fieldschool in Arubo, General Tinio, Nueva Ecija, Central Luzon. Hukay – Bulletin of the University of the Philippines Archaeological Studies Program 4/1, 1-22.

Pawlik, Alfred F. 2002b. Is there an Early Palaeolithic in the Philippines? New approaches for lithic analysis at the Archaeological Studies Program of the University of the Philippines. In M. Horrocks & P. Sheppard (Hrsg.), Australasian connections and new directions: Proceedings of the 7th Australasian Archaeometry Conference. Research in Anthropology and Linguistics Vol. 5. Auckland, New Zealand: University of Auckland, 255-270.

Peebles, Christopher 1993. Aspects of a cognitive archaeology. In Viewpoint: What is cognitive archaeology? Cambridge Archaeological Journal 3/2, 247-270.

Pélégrin, Jacques 1985. Réflexion sur le comportement technique. In Marcel Otte (Hrsg.), La signification culturelle des industries lithiques. Actes du Colloque de Liège du 3 au 7 octobre 1984, Studia Praehistorica Belgica 4. Oxford: BAR International Series 239, 72-91.

Pélégrin, Jacques 1990. Prehistoric lithic technology: some aspects of research. Archaeological Review from Cambridge 9/1, 116-125.

Pélégrin, Jacques 1991. Les savoir-faire: une très longue histoire. Terrain 16, 106-113.

Pélégrin, Jacques 1993. A framework for analysing prehistoric stone tool manufacture and a tentative application to some early stone industries. In A. Berthelet & J. Chavaillon (Hrsg.), The use of tools by human and non-human primates. A Fyssen Foundation Symposium. Oxford: Clarendon Press, 302-317.

Pélégrin, J., C. Karlin & P. Bodu 1988. „Chaînes opératoires“: un outil pour le préhistorien. In J. Tixier (Hrsg.), Technologie lithique, Notes et Monographies Techniques No. 25, Paris: CNRS, 55-62.

Pennisi, Elizabeth 2002. Gene activity clocks brain's fast evolution. Science 296, 233-235.

Perec, Georges (ohne Datum). Anton Voyls Fortgang. Reinbek bei Hamburg: Rowohlt.

Phillips, Kimberley A. 1998. Tool use in wild capuchin monkeys (*Cebus albifrons trinitatis*). American Journal of Primatology 46, 259-261.

Piaget, Jean 1985. Meine Theorie der geistigen Entwicklung. Frankfurt/Main: Fischer.

Pigeot, Nicole 1990. Technical and social actors. Flintknapping specialists and apprentices at Magdalenian Etiolles. Archaeological Review from Cambridge 9/1,126-141.

Pigeot, Nicole 1991. Réflexions sur l'histoire technique de l'homme: de l'évolution cognitive à l'évolution culturelle. Paléo 3, 167-200.

Plooij, Frans 1978. Tool-use by chimpanzees in bushpig hunt. Carnivore 1, 103-106.

Ploux, Sylvie 1989. Approche archéologique de la variabilité des comportements techniques individuels: l'exemple de quelques tailleurs magdaléniens de Pincevent. Paris: Université de Paris X.

Plummer, Thomas 2004. Flaked stones and old bones: biological and cultural evolution at the dawn of technology. Yearbook of Physical Anthropology 47, 118-164.

Plummer, Thomas, Laura C. Bishop, Peter Ditchfield & Jason Hicks 1999. Research on late Pliocene Oldowan sites at Kanjera South, Kenya. Journal of Human Evolution 36, 151-170.

Poeck, Klaus 2002. Apraxie. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 227-239.

Porr, Martin 2000. Signs of time. A different approach towards the origins of Lower Palaeolithic handaxes. Archaeological Review from Cambridge 17/1, 19-32.

Potonié, H. 1913. Die Entstehung der Denkformen. In H. Potonié (Hrsg.), Naturphilosophische Plaudereien. Jena: Gustav Fischer, 70-91.

Potts, Richard 1991. Why the Oldowan? Plio-Pleistocene toolmaking and the transport of resources. Journal of Anthropological Research 47, 153-176.

Potts, Richard, K. A. Behrensmeyer & P. Ditchfield 1999. Paleolandscape variation and Early Pleistocene hominid activities: Members 1 and 7, Olorgesailie Formation, Kenya. Journal of Human Evolution 37, 747-788.

Pruett-Jones, S. G. & M. A. Pruett-Jones 1988. The use of court objects by Lawes' Parotia. The Condor 90, 538-545.

Reader, Simon M. & Kevin N. Laland 2002. Social intelligence, innovation, and enhanced brain size in primates. Proceedings of the National Academy of Science 99/7, 4436-4441.

Renfrew, Colin 1993. Cognitive archaeology: Some thoughts on the archaeology of thoughts. In Viewpoint: What is cognitive archaeology? Cambridge Archaeological Journal 3/2, 247-270.

Renfrew, Colin 1996. The sapient behaviour paradox: How to test for potential? In Paul Mellars & Kathleen R. Gibson (Hrsg.), Modelling the early human mind. Cambridge: The McDonald Institute for Archaeological Research, 11-14.

Renfrew, Colin & Paul Bahn 2000. Archaeology: theories, methods and practice. 3. Aufl. London: Thames & Hudson.

Renfrew, Colin & Chris Scarre (Hrsg.) 1998. Cognition and material culture: the archaeology of symbolic storage. Cambridge: McDonald Institute for Archaeological Research.

Renfrew, Colin & Ezra B.W. Zubrow (Hrsg.) 1994. The ancient mind: elements of cognitive archaeology. Cambridge: Cambridge University Press.

Richter, Daniel, Jürgen Waiblinger, Jack W. Rink & Günther A. Wagner 2000. Thermoluminescence, electron-spin-resonance and ^{14}C dating of the late Middle and early Upper Palaeolithic site of Geissenklösterle Cave in southern Germany. Journal of Archaeological Science 27, 71-89.

Rieder, Hermann 2003. Der große Wurf der frühen Jäger. Biologie unserer Zeit 33/3, 156-160.

Rightmire, G. Philip 2004. Brain size and encephalization in Early to Mid-Pleistocene *Homo*. American Journal of Physical Anthropology 124, 109-123.

Robson Brown, Kate 1993. An alternative approach to cognition in the Lower Palaeolithic: The modular view. Cambridge Archaeological Journal 3/2, 231-245.

Roche, H., A. Delagnes, J.-P. Brugal, C. Feibel, M. Kibunjia, V. Mourre & P.-J. Texier 1999. Early hominid stone tool production and technical skill 2.34 myr ago in West Turkana, Kenya. Nature 399, 57-60.

Roebroeks, W., J. Kolen & E. Rensink 1988. Planning depth, anticipation and the organization of Middle Palaeolithic technology: the "archaic natives" meet Eve's descendants. Helinium 28/1, 17-34.

Ruff, C. B., Erik Trinkaus & T. W. Holliday 1998. Body mass and encephalization in Pleistocene *Homo*. Nature 387, 173-176

Rust, A. 1943. Die alt- und mittelsteinzeitlichen Funde von Stellmoor. Neumünster.

Sabater Pi, Jorge 1974. An elementary industry of the chimpanzees in the Okorobikó Mountains, Rio Muni (Republic of Equatorial Guinea), West Africa. Primates 15/4, 351-364.

Saillot, Isabelle 2002. Analyse paléocognitive de la couche 5 de la Grotte Scladina à Sclayn, Belgique. L'Anthropologie 106, 685-693.

Saillot, Isabelle, Marylène Patou-Mathis & Marcel Otte 2002. Une critique épistémologique des analyses de paléocognition. Préhistoire Européenne 16-17 (2000-2001), 9-15.

Sala, Irene 1996. A study of microscopic polish on flint implements. Oxford: BAR S629.

Santos, Laurie R., Alexandra Rosati, Catherine Sproul, Bailey Spaulding & Marc D. Hauser 2005. Means-means-end tool choice in cotton-top tamarins (*Saguinus oedipus*): finding the limits on primates' knowledge of tools. Animal Cognition 8, 236-246.

Sanz, Crickette, Dave Morgan & Steve Gullick 2004. New insights into chimpanzees, tools, and termites from the Congo Basin. The American Naturalist 164/5, 567-581.

Savage-Rumbaugh, E. Sue et al. 1986. Spontaneous symbol acquisition and communicative use by pygmy chimpanzees (Pan paniscus). Journal of Experimental Psychology 115/3, 214ff.

Savage-Rumbaugh, Sue & Roger Lewin 1998. Kanzi, der sprechende Schimpanse. Was den tierischen vom menschlichen Verstand unterscheidet. München: Knaur.

Savage-Rumbaugh, E. Sue und Duane M. Rumbaugh 1993, The emergence of language. In Kathleen Gibson & Tim Ingold (Hrsg.), Tools, language, and cognition. Cambridge: Cambridge University Press, 86-108.

Schick, Kathy D.& Nicholas Toth 1993. Making silent stones speak: Human evolution and the dawn of technology. London: Weidenfeld and Nicolson.

Schick, Kathy D., Nicholas Toth, Gary Garufi 1999. Continuing investigations into the stone tool-making and tool-using capabilities of a Bonobo (*Pan paniscus*). Journal of Archaeological Science 26, 821-832.

Schlanger, Nathan 1994. Mindful technology: Unleashing the *chaîne opératoire* for an archaeology of mind. In Colin Renfrew & Ezra B. W. Zubrow (Hrsg.), The ancient mind. Elements of cognitive archaeology. Cambridge: Cambridge University Press, 143-151.

Schlanger, Nathan 1996. Understanding Levallois: lithic technology and cognitive archaeology. Cambridge Archaeological Journal 6/2, 231-254.

Schweinfurth, G. 1902. Kieselartefakte in der diluvialen Schotter-Terrasse und auf den Plateauhöhen von Theben. Zeitschrift für Ethnologie 34, 302.

Sellet, F. 1993. Chaîne opératoire: The concept and its applications. Lithic Technology 18/1+2, 106-112.

Semaw, S., P. Renne, W. K. Harris, C. S. Feibel, R. L. Bernor, N. Fesseha & K. Mowbray 1997. 2,5-million-year-old stone tools from Gona, Ethiopia. Nature 385, 333-336.

Semaw, Sileshi, Michael J. Rogers, Jay Quade, Paul R. Renne, Robert F. Butler, Manuel Dominguez-Rodrigo, Dietrich Stout, William S. Hart, Travis Pickering & Scott Simpson 2003. 2.6-Million-year-old stone tools and associated bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. Journal of Human Evolution 45, 169-177.

Senut, Brigitte, Martin Pickford, Dominique Gommery, Pierre Mein, Kiptalam Cheboi & Yves Coppens 2001. First hominid from the Miocene (Lukeino Formation, Kenya). Comtes Rendues de l'Académie des Sciences Paris, Sciences de la Terre et des planètes 332, 137-144.

Shanks, Michael & Ian Hodder 1995. Processual, postprocessual and interpretive archeology. In Ian Hodder, Michael Shanks, A. Alexandri, V. Buchli, J. Carman J. Last & G. Lucas (Hrsg.), Interpreting archaeology: Finding meaning in the Past. London: Routledge, 3-28.

Shea, John J. 1997. Middle Paleolithic spear point technology. In Heidi Knecht (Hrsg.), Projectile technology. New York, London: Plenum Press, 79-106.

Singer, R.& J. Wymer 1982. The Middle Stone Age at Klasies River Mouth in South Africa. Chicago: The University of Chicago Press.

Sloterdijk, Peter 2001. Domestikation des Seins. Für eine Verdeutlichung der Lichtung. In Peter Sloterdijk (Hrsg.), Nicht gerettet. Versuche nach Heidegger. Frankfurt/Main: Suhrkamp, 142-234.

Smith, Richard J. 1996. Biology and body size in human evolution. Statistical inference misapplied. Current Anthropology 37/3, 451-481.

Stanford, Craig B., Galeb Gambaneza, Hohn Bosco Nkurunungi & Michele L. Goldsmith 2000. Chimpanzees in Bwindi-Impenetrable National Park, Uganda, use different tools to obtain different types of honey. Primates 41/3, 337-341.

Steguweit, Leif 1999. Intentionelle Schnittmarken auf Tierknochen von Bilzingsleben – Neue lasermikroskopische Untersuchungen. Praehistoria Thuringica 3, 64-79.

Steguweit, Leif 2003. Gebrauchsspuren an Artefakten der Hominidenfundstelle Bilzingsleben (Thüringen). Tübinger Arbeiten zur Urgeschichte 2. Rhaden/Westfalen: Verlag Marie Leidorf.

Stiles, Daniel 1991. Early hominid behaviour and culture tradition: Raw material studies in Bed II, Olduvai Gorge. The African Archaeological Review 9, 1-19.

Stodiek, Ulrich 1993. Zur Technologie der jungpaläolithischen Speerschleudern. Einer Studie auf der Basis archäologischer, ethnologischer und experimenteller Erkenntnisse. Tübinger Monographien zur Urgeschichte 9. Tübingen: Archaeologica Venatoria.

Stoinski, Tara S. & Benjamin B. Beck (2001). Spontaneous tool use in captive, free ranging gold lion tamarins (*Leontopithecus rosalia rosalia*). Primates 42, 319-326.

Stordeur, D. (Hrsg.) 1987. La main et l'outil: manches et emmanchements préhistoriques. Collection des Travaux de la Maison de l'Orient 15. Lyon: G.S. Maison de l'Orient Méditerranéen.

Stout, Dietrich, Jay Quade, Sileshi Semaw, Michael J. Rogers & Naomi E. Levin 2005. Raw material selectivity of the earliest stone tool makers at Gona, Afar, Ethiopia. Journal of Human Evolution 48, 365-380.

Strum, Shirley C. 1983a. Use of females by male olive baboons (*Papio anubis*). American Journal of Primatology 5, 93-109.

Strum, Shirley C. 1983b. Baboon cues for meat eating. Journal of Human Evolution 12,327 336.

Sturm, Walter & Wolfgang Hartje 2002. Experimentelle und klinische Neuropsychologie. In Wolfgang Hartje & Klaus Poeck (Hrsg.), Klinische Neuropsychologie. 5. überarb. und erw. Aufl. Stuttgart, New York: Thieme, 1-51.

Sugiyama, Yukimaru 1985. The brush-stick of Chimpanzees found in South-West Cameroon and their cultural characteristics. Primates 26, 361-374.

Sugiyama, Yukimaru 1997. Social tradition and the use of tool-composites by wild chimpanzees. Evolutionary Anthropology 6, 23-27.

Sumita, Kyoko, Jean Kitahara-Frisch & Kohshi Norikoshi 1985. The acquisition of stone-tool use in captive chimpanzees. Primates 26/2, 168-181.

Susman, Randall L. 1991. Who made the Oldowan tools? Fossil evidence for tool behavior in Plio-Pleistocene hominids. Journal of Anthropological Research 47, 129-151.

Susman, Randall L. 1994. Fossil evidence for early hominid tool use. Science 265, 1570 1573.

Susman, R. L. 1998. Hand function and tool behavior in early hominids. Journal of Human Evolution 35/1, 23-46.

Takemoto, Hiroyuki, Satoshi Hirata & Yukimaru Sugiyama 2005. The formation of the brush sticks: modification of chimpanzees or the by-product of folding? Primates 46, 183-189.

Takeshita, Hideko & Jan A. R. A. M. van Hoof 2001. Tool use by chimpanzees (Pan troglodytes) of the Arnhem Zoo community. In Tetsuro Matsuzawa (Hrsg.), Primate origins of human cognition and behavior. Tokyo: Springer, 519-536.

Tattersall, Ian 2001. How we came to be human? (Book excerpt from "The monkey in the mirror: Essays on the science of what makes us human. Harcourt 2002). Scientific American 12/2991, 42-49.

Tebbich, Sabine, Michael Taborsky, Birgit Fessl & Donald Blomqvist 2001. Do woodpecker finches acquire tool-use by social learning? Proceedings of the Royal Society of London B 268, 2189-2193.

Teleki, Geza 1974. Chimpanzee subsistence technology: materials and skills. Journal of Human Evolution 3/6, 575-594.

Terberger, Thomas, Martin Street & Günther Bräuer 2001. Der menschliche Schädelrest aus der Elbe bei Hahnöfersand und seine Bedeutung für die Steinzeit Norddeutschlands. Archäologisches Korrespondenzblatt 31, 521-526.

Teyssandier, Nicolas 2004. Les débuts de l'aurignacien en Europe. Discussion à partir des sites de Geissenklösterle, Willendorf II, Krems-Hundsteig et Bacho Kiro. Unpubl. Dissertation.

Thieme, Hartmut 1997. Lower Paleolithic hunting spears from Germany. Nature 385, 807 810.

Thieme, Hartmut 1998. Altpaläolithische Wurfspeere von Schöningen, Niedersachsen. Praehistoria Thuringica 2, 22-31.

Thieme, Hartmut 1999. Altpaläolithische Holzgeräte aus Schöningen, Lkr. Helmstedt. Germania 77/2, 451-487.

Thieme, Hartmut & Stephan Veil 1985. Neue Untersuchungen zum eemzeitlichen Elefanten Jagdplatz Lehringen, Ldkr. Verden. Die Kunde N.F. 36, 11-58.

Tobias, Philipp V. 1995, The communication of the dead: Earliest vestiges of the origin of articulate language. 17. Kroon-Vordracht 17.3.1995. Amsterdam: Stichting Nederlands Museum voor Anthropologie en Praehistorie.

Tomasello, Michael 1990. Cultural transmission in the tool use and communicatory signalling of chimpanzees ? In Sue Taylor Parker & Kathleen R. Gibson (Hrsg.), “Language” and intelligence in monkeys and apes: Comparative developmental perspectives. Cambridge: Cambridge University Press, 274-311.

Tomasello, Michael 2002. Die kulturelle Entwicklung des menschlichen Denkens. Zur Evolution der Kognition. Frankfurt/M.: Suhrkamp.

Tomasello, Michael, M. Davis-Dsilva, L. Camak & K. Bard 1987. Observational learning of tool-use by young chimpanzees. Human Evolution 2/2, 175-183.

Tonooka, Rikako 2001. Leaf-folding behaviour for drinking water by wild chimpanzees (*Pan troglodytes verus*) at Bossou, Guinea. Animal Cognition 4, 325-334.

Tooby, John & Leda Cosmides 1992. The psychological foundations of culture. In Jerome H. Barkow, Leda Cosmides & John Tooby (Hrsg.), The adapted mind. Evolutionary psychology and the generation of culture. New York, Oxford : Oxford University Press, 19-136.

Torre, Ignacio de la, Rafael Mora, Manuel Domínguez-Rodrigo, Luis de Luque & Luis Alcalá 2003. The Oldowan industry of Peninj and its bearing on the reconstruction of the technological skills of Lower Pleistocene hominids. Journal of Human Evolution 44, 203-224.

Toth, Nicholas 1985. The Oldowan reassessed: a close look at Early Stone Age artefacts. Journal of Archaeological Science 12, 101-120.

Toth, Nicholas, Kathy D. Schick, E. S. Savage-Rumbaugh, R. A. Sevcik & D. Rumbaugh 1993. Pan the tool-maker: Investigations into the stone tool-making and tool-using capabilities of a Bonobo (*Pan paniscus)*. Journal of Archaeological Science 20, 81-91.

Trinkaus, Erik (Hrsg.) 1989, The Emergence of modern humans: biocultural adaptations in the Later Pleistocene. Cambridge: Cambridge University Press.

Trinkaus, Erik, Stefan Milota, Ricardo Rodrigo, Gherase Mircea & Oana Moldovan 2003. Early modern human cranial remains from Pestera cu Oase, Romania. Journal of Human Evolution 45, 245-253.

Tromnau, Gernot 1983. Ein Mammutknochen-Faustkeil aus Rhede/Kreis Borken (Westfalen). Archäologisches Korrespondenzblatt 13, 287-289.
Uehara 1982

Ueno, Yoshikazu & Kazuo Fujita 1998. Spontaneous tool use by a Tonkean macaque (*Macaca tonkeana*). Folia primatologica 69, 318-324.

van der Leuw, S. E. 1994. Cognitive aspects of 'technique'. In Colin Renfrew & Ezra B. W. Zubrow (Hrsg.), The ancient mind. Elements of cognitive archaeology. Cambridge: cambridge uNiversity Press, 135-142.

van Lawick-Goodall, Jane 1970. Tool-using in primates and other vertebrates. In Lehrman, Hinde & Shaw (Hrsg.), Advances in the study of behavior Vol. 3. London: Academic Press, 195-249.

van Lawick-Goodall, Jane & Hugo van Lawick-Goodall 1966. Use of tools by the Egyptian Vulture, *Neophron percnopterus*. Nature 212, 1468-1469.

van Lawick-Goodall, Jane, Hugo van Lawick-Goodall & C. Parker 1973. Tool-use in free living baboons in the Gombe National Park, Tanzania. Nature 241, 212-213.

van Peer, P., R. Fullagar, S. Stokes, R. M. Bailey, J. Moeyersons, F. Steenhoudt, A.Geerts, T. Vanderbeken, M. de Dapper & F. Geus 2003. The Early to Middle Stone Age transition and the emergence of modern human behavior at site 8-B-11, Sai Island, Sudan. Journal of Human Evolution 45,187-193.

van Schaik, Carel P., Marc Ancrenaz, Gwendolyn Borgen, Birute Galdikas, Cheryl D. Knott, Ian Singleton, Akira Suzuki, Sri Suci Utami & Michelle Merrill 2003. Orangutan cultures and the evolution of material culture. Science 299, 102-105.

van Schaik, Carel P., R. O. Deaner & M. Y. Merrill 1999. The conditions for tool use in primates: Implications for the evolution of material culture. Journal of Human Evolution 36, 719-741.

van Schaik, Carel P., Elizabeth A. Fox & A. F. Sitompul 1996. Manufacture and use of tools in wild Sumatran orangutans. Die Naturwissenschaften 83, 186-188.

van Schaik, Carel P. & Cheryl D. Knott 2001. Geographic variation in tool use on Neesia fruits in orangutans. American Journal of Physical Anthropology 114, 331-342.

Varela, Francisco J. 1990. Kognitionswissenschaft – Kognitionstechnik. Eine Skizze aktueller Perspektiven. Frankfurt/M., Suhrkamp.

Veil, Stephan 1991. Die Nachbildung der Lanze von Lehringen. Experimente zur Holzbearbeitung im Mittelpaläolithikum. Die Kunde N.F. 41/42, 9-22.

Veil, Stephan, Gabriele Lass & Karl Josef Narr 1988. Was man mit dem Faustkeil machte. Mikroskopische Gebrauchsspurenuntersuchungen an Steinwerkzeugen in Niedersachsen. Die Kunde N.F. 39, 255-264.

Vekua, Abesalom, David Lordkipanidze, G. Philip Rightmire, Jordi Augusti, Reid Ferring, Givi Maisuradze, Alexander Mouskhelishvili, Medea Nioridze, Marcia Ponce de Leon, Martha Tappen, Merab Tvalchrelidze, Christoph Zollikofer 2002. A new skull of early Homo from Damanisi, Georgia. Science 297, 85-89.

Verworn, Max 1915. Die Entwicklung des menschlichen Geistes. 3. Aufl. Jena: Gustav Fischer.

Veselovsky, Z. 1978. Beobachtungen zu Biologie und Verhalten des Großen Kragenlaubenvogels (*Chlamydera nuchalis*). Journal für Ornithologie 119, 74-90.

Villa, Paola 1983. Terra Amata and the Middle Pleistocene archaeological record of Southern France. Berkeley: University of California Press.

Villa, Paola 1991. Middle Pleistocene prehistory in Southwestern Europe: The state of our knowledge and ignorance. Journal of Anthropological Research 47, 193-217.

Villa, Paola & Francesco d'Errico 2001. Bone and ivory points in the Lower and Middle Paleolithic of Europe. Journal of Human Evolution 41, 69-112.

Visalberghi, Elisabetta & Luca Limongelli 1996. Acting and understanding: Tool use revisited through the minds of capuchin monkeys. In Russon, Anne E., Kim A. Bard & Sue Taylor Parker (Hrsg.), Reaching into thought. The minds of the great apes. Cambridge: Cambridge University Press, 57-79.

von Frisch, K. 1974. Animal architecture. New York: Harcourt Brace Jovanovich.

Wadley, Lyn 2001. What is cultural modernity? A general view and a South African perspective from Rose Cottage Cave. Cambridge Archaeological Journal 11/2, 201-221.

Wadley, Lyn 2005. Putting ochre to the test: replication studies of adhesives that may have been used for hafting tools in the Middle Stone Age. Journal of Human Evolution 49/5, 587-601.

Walter, R. C., P. C. Manega, R. L. Hay, R. E. Drake & G. H. Curtis 1991. Laser-fusion ^{40}Ar/^{39}Ar dating of Bed I, Olduvai Gorge, Tanzania. Nature 354, 145-149.

Washburn, S. L.& Phyllis C. Jay 1967. More on tool-use among primates. Current Anthropology 8/3, 253-257.

Weiner, Jürgen 1991. Wo sind die Retorten? Überlegungen zur Herstellung von Birkenpech im Neolithikum. Acta Prehistorica et Archaeologica 23, 15-19.

Weiner, Steve, Qingi Xu, Paul Goldberg, Jinyi Liu & Ofer Bar-Yosef 1998. Evidence for the use of fire at Zhoukoudian, China. Science 281, 251-253.

Weir, Alex A. S., Jackie Chappell & Alex Kacelnik 2002. Shaping of hooks in New Caledionan crows. Science 297, 981.

Weldon, P. J. & Hoffmann, D. L. 1975. Unique form of tool-using in two gastropod molluscs (Trochidae). Nature 256, 720-721.

Westergaard, Gregory Charles 1995. The stone-tool technology of capuchin monkeys: possible implications for the evolution of symbolic communication in hominids. World Archaeology 27/1, 1-9.

Westergaard, Gregory Charles & Stephen J. Suomi 1995. The manufacture and use of bamboo tools by monkeys: possible implications for the development of material culture among East Asian hominids. Journal of Archaeological Science 22, 677-681.

Whallon, R. 1989. Elements of cultural change in the later Palaeolithic. In Paul Mellars & Chris Stringer (Hrsg.), The human revolution: Behavioural and biological perspectives on the origins of modern humans. Princeton: Princeton University Press, 433-454.

White, Leslie A. 1942. On the use of tools by primates. The Journal of Comparative Psychology 34, 369-374.

White, Mark J. 2000. The Clactonian question: On the interpretation of core-and-flake assemblages in the British Lower Paleolithic. Journal of World Prehistory 14/1, 1-63.

White, Mark & Nick Ashton 2003. Lower Palaeolithic core technology and the origins of the Levallois method in North-Western Europe. Current Anthropology 44/4, 598-609.

White, Randall 2001. Personal ornaments from the Grotte du Renne at Arcy-sur-Cure. Athena Review 2, 41-46.

White, Tim D., Berhane Asfaw, David DeGusta, Henry Gilbert, Gary D. Richards, Gen Suwa & F. Clark Howell 2003. Pleistocene Homo sapiens from Middle Awash, Ethiopia. Nature 423, 742-747.

Whiten, Andrew 2005. The second ineritance system of chimpanzees and humans. Nature 437, 52-55.

Whiten, Andrew & Christophe Boesch 2001. Die Kultur der Schimpansen. Spektrum der Wissenschaft April 2001, 30-38.

Whiten, A., J. Goodall, W. C. McGrew, T. Nishida, V. Reynolds, Y. Sugiyama, C. E. G. Tutin, R. W. Wrangham & C. Boesch 1999. Cultures in chimpanzees. Nature 399, 682-685.

Whiten, A., J. Goodall, W. C. McGrew, T. Nishida, V. Reynolds, Y. Sugiyama, C. E. G. Tutin, R. W. Wrangham & C. Boesch 2001. Charting cultural variation in chimpanzees. Behaviour 138, 1481-1516.

Whiten, Andrew, Victoria Horner & Sarah Marshall-Pescini 2003. Cultural Panthropology. Evolutionary Anthropology 12, 92-105.

Whiten, Andrew 2005. The second inheritance system of chimpanzees and humans. Nature 437, 52-55.

Whitley, David S. 1998a. New approaches to old problems. Archaeology in search of an ever elusive past. In David S. Whitley (Hrsg.), Reader in archaeological theory – postprocessual and cognitive archaeology. London, New York: Routledge, 1-28.

Whitley, David S. 1998b. Prehistoric cognition. In David S. Whitley (Hrsg.), Reader in archaeological theory – postprocessual and cognitive archaeology. London, New York: Routledge, 133-136.

Wild, Eva, Maria Teschler-Nicola, Walter Kutschera, Peter Steier, Erik Trinkaus & Wolfgang Wanek 2005. Direct dating of early Upper Paleolithic human remains from Mladeč. Nature 435, 332-335.

Wildman, Derek E., Monica Uddin, Guozhen Liu, Lawrence I. Grossman & Morris Goodman 2003. Implications of natural selection in shaping 99.4% nonsynonymous DNA identity between humans and chimpanzees: Enlarging genus *Homo*. Proceedings of the National Academy of Science 100/12, 7181-7188.

Wilkins, Wendy K. & Jennie Wakefield 1995. Brain evolution and neurolinguistic preconditions. Behavioral and Brain Sciences 18, 161-226.

Wood, Bernard 2002. Hominid relevations from Chad. Nature 418, 133-135.

Wrangham, R. W., W. C. McGrew, Frans B.W. deWaal & P. G. Heltne 1994. Chimpanzee cultures. Cambridge, Mass.: Harvard University Press.

Wright, R. V. A. 1972. Imitative learning of a flaked stone technology – the case of an orang utan. Mankind 8, 296-306.

Wuketits, Franz M. 1988. Evolutionstheorien. Historische Voraussetzungen, Positionen, Kritik. Darmstadt: Wissenschaftliche Buchgesellschaft.

Wynn, Thomas 1979. The intelligence of later Acheulean hominids. Man 14, 371-391.

Wynn, Thomas 1981. The intelligence of Oldowan hominids. Journal of Human Evolution 10, 529-541.

Wynn, Thomas 1985. Piaget, stone tools and the evolution of human intelligence. World Archaeology 17, 32-43.

Wynn, Thomas 1990. Natural history and the superorganic in studies of tool behavior. In Marc Bekoff & Dale Jamieson (Hrsg.), Interpretation and explanation in the study of animal behavior, Vol. II: Explanation, evolution, and adaptation. Boulder: Westview Press, 98-117.

Wynn, Thomas 1991. Tools, grammar, and the archaeology of cognition. Cambridge Archaeological Journal ½, 191-206.

Wynn, Thomas 1993.Two developments in the mind of early Homo. Journal of Anthropological Archaeology 12, 299-322.

Wynn, Thomas 1995. Handaxe enigmas. World Archaeology 27/1, 10-24.

Wynn, Thomas & McGrew, William C. 1989. An ape’s view of the Oldowan. Man 24, 383 398.

Yamada, S. 1999. Announcement of the symposium ‘Reappraisal of Early and Middle Paleolithic human cognitive ability: The lithic and geological evidence from Kamitakamori and other Paleolithic sites in Northern Japan’. Society for American Archaeology 1999 Annual Meeting. Chicago, 24.-28. März 1999.

Yamakoshi, Gen 2001. Ecology of tool use in wild chimpanzees: Toward reconstruction of early hominid evolution. In Tetsuro Matsuzawa (Hrsg.), Primate origins of human cognition and behavior. Tokyo: Springer, 537-556.

Yamakoshi, Gen & Yukimaru Sugiyama 1995. Pestle-pounding behavior of wild chimpanzees at Bossou, Guinea: a newly observed tool-using behavior. Primates 36/4, 489-500.

Yellen, John E. Allison S. Brooks. Els Cornelissen, Michael J. Mehlman & Kathlyn Stewart 1995. Middle Stone Age worked bone industry from Katanda, upper Semliki valley, Zaire. Science 268, 553-556.

Yerkes, Robert 1916. The mental life of monkeys and apes: A study of ideational behavior. Baltimore: Behavior Monographs 3.

Yerkes, Robert M. & Blanche W. Learned 1925. Chimpanzee intelligence and its vocal expressions. Baltimore: Williams and Wilkins.

Yerkes, Robert M. & Ada W. Yerkes 1929. The great apes. A study of anthropoid life New Haven: Yale University Press.

Zollikofer, Christoph P. E., Marcia S. Ponce de León, Daniel. E. Lieberman, Franck Guy, David Pilbeam, Andossa Likius, Hassane T. Mackaye, Patrick Vignaud & Michel Brunet 2005. Virtual cranial reconstruction of Sahelanthropus tchadensis. Nature 434, 755-759.

ISBN 978-3-00-036638-3