

# COGNITIVE ARCHAEOLOGY *and* HUMAN EVOLUTION



*Edited by*  
*Sophie A. de Beaune*  
*Frederick L. Coolidge*  
*Thomas Wynn*

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## COGNITIVE ARCHAEOLOGY AND HUMAN EVOLUTION

This book presents new directions in the study of cognitive archaeology. Seeking to understand the conditions that led to the development of a variety of cognitive processes during evolution, it uses evidence from empirical studies and offers theoretical speculations about the evolution of modern thinking as well. The volume draws from the fields of archaeology and neuropsychology, which traditionally have shared little in the way of theories and methods, even though both disciplines provide crucial pieces to the puzzle of the emergence and evolution of human cognition. The twelve essays, written by an international team of scholars, represent an eclectic array of interests, methods, and theories about evolutionary cognitive archaeology. Collectively, they consider whether the processes in the development of human cognition simply made use of anatomical and cerebral structures already in place at the beginning of hominization. They also consider the possibility of an active role of hominoids in their own development and query the impact of hominoid activity in the emergence of new cognitive abilities.

Sophie A. de Beaune is Professor of Prehistory at Jean Moulin University – Lyon 3 and Deputy Scientific Director at the French National Center for Scientific Research (CNRS). The author of eight books, most recently *L'Homme et L'outil: L'invention Technique durant la Préhistoire*, she is also director of a book series entitled “Le passé recomposé” at CNRS Editions.

Frederick L. Coolidge is Professor of Psychology at the University of Colorado at Colorado Springs. He has published extensively in behavioral genetics, neuropsychology, psychopathology assessment, and cognitive archaeology, with recent articles in *Cambridge Archaeological Journal*, the *Journal of Human Evolution*, and *Journal of Archaeological Research*, among others.

Thomas Wynn is Professor of Anthropology at the University of Colorado at Colorado Springs. He has published extensively on the evolution of human cognition, culminating in a target article in *Behavioral and Brain Sciences*, published in 2002.

# Cognitive Archaeology and Human Evolution

Edited by

**SOPHIE A. DE BEAUNE**

Jean Moulin University – Lyon 3 and CNRS

**FREDERICK L. COOLIDGE**

University of Colorado, Colorado Springs

**THOMAS WYNN**

University of Colorado, Colorado Springs



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## Contributors

**Sophie A. de Beaune** is Professor of Prehistory at Jean Moulin University – Lyon 3 (France). She was educated at the Pantheon-Sorbonne University of Paris I and is a researcher at the French National Center for Scientific Research (CNRS) unit Archéologies et Sciences de l'Antiquité (ArScAn) in Nanterre, France. She is currently working on Upper Palaeolithic technology, the evolution of technology, and the link between archaeology and cognition. She recently published *L'Homme et L'outil: L'invention Technique durant la Préhistoire* (CNRS Ed., 2008). In 2009, she was appointed Deputy Scientific Director at the CNRS.

**Carmine Collina** is a prehistoric archaeologist. He is completing a doctoral thesis at the University of Provence and University La Sapienza of Rome. He is a member of the Italian Archaeological Mission of Melka Kunture (Ethiopia). Among others, he studies the lithic technology of Oldowan and Acheulean industries in Eastern Africa. In 2008, he published with Marcello Piperno and others “Obsidian Exploitation and Utilization During the Oldowan at Melka Kunture (Ethiopia),” in E. Hovers and D. R. Braun (Eds.), *Interdisciplinary Approaches to the Oldowan* (Springer Science, Business Media B.V., 111–128).

**Frederick L. Coolidge** received his doctorate from the University of Florida and completed a two-year Postdoctoral Fellowship in Clinical Neuropsychology at Shands Teaching Hospital, Gainesville, Florida. He is currently Professor of Psychology at the University of Colorado at Colorado Springs. Professor Coolidge conducts research in behavioral genetics and psychological assessment. For the past ten years, he has been interested in the application of cognitive and psychological models to archaeology. He and

archaeologist Thomas Wynn recently published a paper in the journal *PalaeoAnthropology* titled “The Role of Episodic Memory and Autozoetic Thought in Upper Palaeolithic Life.”

**Miriam Noël Haidle** received her doctoral and habilitation degrees from the University of Tübingen, Germany, in 1996 and 2006. She is currently the coordinator of The Role of Culture in Early Expansions of Humans Research Center of the Heidelberg Academy of Sciences and Humanities. Specializing in the evolution of the mind, she has in press “Working Memory Capacity and the Evolution of Modern Cognitive Capacities: Implications from Animal and Early Human Tool Use,” in T. Wynn and F. Coolidge (Eds.), *Working Memory and the Evolution of Modern Thinking* (Current Anthropology).

**Andreas Kyriacou**, Neuropsychology Unit, University Hospital of Zürich, received his Master’s Degree in Science in clinical linguistics from the Universities of Potsdam, Germany, and Groningen, The Netherlands. For his doctorate at the Center for Neuroscience in Zürich, Switzerland, he investigated proneness to false memories in skeptical and schizotypal thinkers. His main interest lies in the neural underpinnings of creativity and madness. In 2004, he published “How Thinking Determines Language: The Relativity of Language Relativity,” in G. Fulton, W. J. Sullivan, and A. R. Lommel (Eds.), *Language, Thought and Reality* (LACUS, 159–165).

**Carolina Maestro** is a prehistoric archaeologist. In 2007, she received a postgraduate degree in Prehistory at the National Archaeological School of the University La Sapienza of Rome with this dissertation: “Origins and Diffusion of *Homo sapiens*: The Debate on Emergence of Behavioral Modernity.” She is currently a doctoral student in Cognitive Archaeology at the University of Montreal. Her research is about first symbolic manifestations of the Middle and Upper Palaeolithic.

**Jacques Pelegrin** completed his doctorate in Prehistory in 1986 at the University of Nanterre (Paris X), about the Châtelperronian. Presently a Research Director in the Préhistoire et Technologie Laboratory of the French National Center for Scientific Research – University of Paris X, he is a specialist in lithic techniques, with a particular interest in methodological and cognitive implications. In 2005, he published “Remarks About Archaeological Techniques and Methods of Knapping: Elements of a Cognitive Approach to Stone Knapping,” in V. Roux and B. Bril (Eds.), *Stone*

*Knapping: The Necessary Condition for a Uniquely Hominid Behaviour* (MacDonald Institute, 23–33).

**Eric Reuland** received his doctorate in Linguistics from the University of Gröningen in 1979. He is currently Faculty Professor of Language and Cognition in the Faculty of Humanities of Utrecht University. His main area of research is the relation between the syntactic system of human language and the interpretive and processing systems. He recently became intrigued by the question of how language could have originated. In 2005, he published “On the Evolution and Genesis of Language: The Force of Imagination,” in the journal *Lingue e Linguaggio* (1, 81–110).

**Matt J. Rossano** received his doctorate in Psychology from the University of California at Riverside in 1991. He is currently Professor of Psychology and Department Head at Southeastern Louisiana University in Hammond. He is an evolutionary psychologist specializing in the evolution of the mind, religion, and consciousness. In 2007, he published “Did Meditating Make Us Human?” in the *Cambridge Archaeological Journal* (17, 47–58).

**Ian Tattersall** received his doctorate from Yale University, in 1971, about the Subfossil Lemurs of Madagascar. He is currently Curator at the American Museum of Natural History, New York. He is working to document the major fossils in the human fossil record. He is also continuing his independent inquiries into the nature and emergence of modern human cognition. In 2008, he published, with R. DeSalle, *Human Origins: What Bones and Genomes Tell Us About Ourselves* (A&M University Press).

**Natalie T. Uomini** received her doctorate from the University of Southampton, UK, and is currently a Postdoctoral Researcher at Liverpool University with the Lucy to Language project. She is interested in the origins of language and how it relates to hand preference and brain lateralization. Her research combines archaeology, cognitive science, psycholinguistics, and primatology. In 2008, she published “The Evolution of Handedness in Humans and Great Apes: A Review and Current Issues,” in *Journal of Anthropological Sciences* (86, 1–30), with L. Cashmore and A. Chapelain.

**Michael J. Walker** graduated from Oxford University in Medicine, Physiology, and Prehistoric Archaeology, receiving his doctorate in Philosophy in 1973. He is currently Professor of Physical Anthropology at Murcia

University in Spain, where he directs field research at two Neanderthal sites. In 2006, he published “Cueva Negra del Estrecho del Río Quípar (Murcia, Southeast Spain): An Acheulian and Levalloiso-Mousteroid Assemblage of Palaeolithic Artifacts Excavated in a Middle Pleistocene Faunal Context with Hominin Skeletal Remains,” in the journal *Eurasian Prehistory* (4, 3–43).

**Thomas Wynn** earned his doctorate in Anthropology at the University of Illinois, Urbana-Champaign, in 1977. He was one of the few who established cognitive archaeology as a viable approach in palaeoanthropology. He has published extensively on the evolution of human cognition, culminating in a target article in 2002: “Archaeology and Cognitive Evolution,” in the journal *Behavioral and Brain Sciences* (25, 3, 389–438). More recently, he has teamed with psychologist Frederick L. Coolidge to investigate the evolution of the modern mind, with an emphasis on executive functions and working memory. Thomas Wynn is currently Professor of Anthropology at the University of Colorado, Colorado Springs.

## COGNITIVE ARCHAEOLOGY AND HUMAN EVOLUTION

## CHAPTER 1

# The emergence of cognitive abilities: The contribution of neuropsychology to archaeology

*Sophie A. de Beaune*

The cognitive abilities of the ancient hominins appear to have progressed relatively slowly, insofar as the material evidence that they left behind is concerned. In fact, their technical productions, which appeared more than 2.5 million years ago, improved very little for nearly the entire period (i.e., about 2 million years). In contrast, the evidence of nonutilitarian practices, such as the burial of the dead or the first graphic expressions, made their appearance much later, not before 100,000 years ago. In addition, the human fossils themselves indicate a gradual evolution of uniform growth of the brain size.

We can query about the emergence conditions of these material and “symbolic” productions and ask why only the human species could develop it. If we admit that they reflect a modification of cognitive skills, then it is advisable to wonder of what these capacities consist. We could thus question the capacities of anticipation of the handaxe toolmakers or the capacities of abstraction and symbolization of the first people who buried their dead.

We could also seek to understand the conditions that led to the installation of a variety of cognitive processes during evolution. Are the processes developed answers to the requests of a changing environment, or are they the result of an evolution of the neurophysiological organization of the brain? Were the processes simply a better use of anatomical and cerebral structures already installed at the beginnings of the hominization? It is also possible to consider a more active role of hominins in their own development and to query about the impact of their activity in the emergence of new cognitive abilities.

One can also ask whether there is something specific to the human species that could explain why the nearest relatives of the hominins, the apes, do not seem to have access to such cognitive aptitudes, at least not in such a developed and systematic manner. Are these differences the result of simply diverging processes in species with equivalent potentialities at the beginning? Are there neurophysiologic differences important enough to explain these differences in ability? Or is it the aptitude to transmit their knowledge to the following generations that would distinguish the human primates from the nonhuman primates?

All of these questions and many others deserve to be debated. This is why it seemed to us that it could be profitable to gather prehistorians and neuropsychologists, both interested in the question of the emergence and evolution of cognitive abilities, so that they could confront and share their points of view and their knowledge.

This book<sup>1</sup> presents the results of both empirical studies and theoretical speculations about the emergence and the evolution of modern thinking, with evidence coming from both archaeology and neuropsychology. We explore the cognitions required in the making of simple stone tools to more sophisticated production, such as symbolic thought or language. Traditionally, these two fields of study have shared little in the way of theories and methods, yet they both provide crucial pieces to the puzzle of modern human cognitive emergence and evolution.

Cognitive archaeology is a quickly growing discipline. Ironically, archaeologists have been slow to adopt current theories, models, and findings within contemporary cognitive science. This book will serve as an example of the contributions of both disciplines.

1 Some of these chapters were presented as papers at the Congress of the International Union for Prehistoric and Protohistoric Sciences (IUPPS) in Lisbon, Portugal, on September 7, 2006, at a colloquium organized by Sophie A. de Beaune.

## CHAPTER 2

# Technical invention in the Palaeolithic: What if the explanation comes from the cognitive and neuropsychological sciences?

*Sophie A. de Beaune*

The evolution of the cerebral capacities of humans, from the first hominins to modern humans, is at the heart of our interrogations. How can we explain the fact that only hominins seem to have developed the capacity for technical invention, in contrast to our closest relatives, the great apes? The archaeological data allow us to observe this phenomenon, but offer very little in the way of a response to this question.

By examining the possible contributions of other disciplines, particularly in the cognitive and neuropsychological sciences, we can ask if there exists a cause-and-effect relationship between the following phenomena:

- the archaeological data, which indicate that technical inventions throughout prehistory are increasingly frequent and complex from the first hominins to modern humans;
- the cognitive perspective, which seems to indicate that the processes of analogical reasoning are increasingly frequent through time, either for “statistical” reasons (a greater population density leads to a greater probability of the meeting of two ideas) or for cognitive reasons; and
- the palaeoanthropological data, which show that current neurological conditions developed progressively, with the frontal lobes and pre-frontal cortex becoming more and more accentuated from the first hominins to modern humans.

We will explore the possible contribution of a confrontation of these different disciplines.

### Invention processes: The archaeological data

Through the study of a certain category of archaeological remains – stone tools that are not flint – I have shown that the invention of new tools and new actions seems to have resulted from a combination of preexisting elements, rather than from creations *ex nihilo*, or an accumulation of knowledge. They were made possible by the fusion of two different technical actions, by the combination of a familiar action with a tool traditionally used for other purposes, or by the combination of a familiar tool with a new worked material (de Beaune 2000, 2004, 2008). To briefly recapitulate this process, I will present some examples, the first of which comes from my own investigations of nonflint stone tools.

During the Neolithic period, the technique of polishing with a fixed polisher on bedrock was extensively used to polish ax blades. This technique could be the result of a fusion of the technique of polishing long objects with a small, generally grooved, hand polisher during the Upper Palaeolithic and Mesolithic, and the full back-and-forth grinding technique, generally realized with two hands, which appeared at the end of the Upper Palaeolithic or Epipalaeolithic and was first used to grind wild cereal grains (de Beaune 2000, 186–187).

Pottery seems to have resulted from a combination of the idea of a container (which already existed in the form of skin, vegetal fiber, bark, and wood containers) and the baked-clay technique. Baked clay was already used as a coating for walls and floors, and later as an internal facing of pit hearths as early as the second phase of Mureybet, and then to shape figurines starting in Mureybet Phase IIIA (Cauvin 1978, 101; 1994, 64).

Another much earlier example has been proposed by Despina Liolios in the context of antler-working techniques, which would have been transferred from wood to antler during the early Aurignacian period (Liolios 2003).

Much further back in time, we could include the first attempts at bone shaping during the Middle or Early Palaeolithic, which consisted of no more than knapping techniques transferred from flint to bone. The result was the crude bone bifaces or bone side scrapers found in several sites, such as Castel di Guido and Fontana Ranuccio in Italy and Bilzingsleben in Thüringen, Germany (Biddittu & Segre 1982; Pitti & Radmilli 1984; Mania 1995).

We thus see that from the Early Palaeolithic to the Neolithic, innovations or inventions seem to have resulted from the same process of technical

transfer, meaning the combination of two already existing, but independent, technical ideas. These combinations did not arise from nothing, but rather from an association in the mind of things until then dissociated in experience.

In this way, the increase and diversification of inventions and innovations through time could simply have resulted from a demographic increase, which favored the opportunity for technical confrontations. However, we must keep in mind that the combination of two technical ideas is neither systematic nor necessary, and that it is possible for two ideas never to meet (for example, the idea of the wheel and that of the carriage for the ancient Mexicans).

In the same way, an “invention” can remain with no outcome if it is not adopted by the group, and in this case it is very unlikely that it would be recognized by archaeologists.

The term “exaptation” introduced by Stephen Jay Gould and Elizabeth Vrba (Gould & Vrba 1982) designates something that emerges from a context before its exploitation in another one. In other words, the word defines the choice in the present to use elements initially destined for other functions (or no function) for certain purposes. As an example, they cite the case of an African lizard whose extremely flat head constitutes an adaptation to life in crevices, but which also permits the animal to slide better.

Exaptation is in a way opposed to adaptation because, whereas adaptation implies a modification of a function to allow different uses, exaptation is the adoption of a character that had one use in an ancestral form and a new and different use in a descendant form.

Exaptation could explain how complex physical characteristics can evolve from initial simple structures. In fact, the term better clarifies the technical invention process in question here.

### **Invention processes: The cognitive perspective**

These few examples of technical inventions could result from the well-known cognitive capacity of analogy. To cite Le Ny from his preface to the book *Analogie et Cognition*, “analogy, in its broad sense, and its cousin, resemblance (or similarity), is probably the basis of many automatic cognitive activities, and I am not far from thinking that it is one of the fundamental determinants of cognitive functioning” (Le Ny 1999, x). More precisely, the functioning of analogy in problem solving, in the generation of scientific

hypotheses, or in declarative knowledge attainment, as in many other cognitive domains, is always based on the capacity to perceive and use analogous facts. In other words, it is based on the capacity to establish a link between two domains and transfer a familiar procedure from one situation or class of situations to a new situation that is similar though not identical (Le Ny 1999, xiv).

The three following questions thus arise: What exactly is the process of analogical reasoning? Is it specific to humans? If so, when did it appear?

### *What is the analogical process?*

The analogical process can easily be summarized as follows: When people are faced with a new situation or problem, they look for a similar problem or situation in their anterior experience for which they had found a good solution.

This strategy implies two types of mental representation: those stocked in the long-term memory, and transitory representations, meaning those used during information treatment that correspond to the working memory, including old representations reactivated in the moment of their treatment.

Although referential knowledge is essential, two other cognitive tools are also necessary for its utilization: abstraction and generalization (Gineste 1997, 86, 119).

Obviously, differences exist between a so-called expert, who has already confronted an analogous problem and who possesses structured and stabilized knowledge in the long-term memory, and a novice confronted with a new problem. The latter must establish a link between two domains and transfer a familiar procedure from one situation or class of situations to a new situation that is similar though not identical.

In spite of some minor theoretical differences, most cognitive psychologists agree on the manner in which the analogical process functions and its importance in the processes of invention and problem solving.

### *Is analogical reasoning specific to humans?*

Chimpanzees occasionally use transfer to solve a problem or a situation. However, this capacity, known as competence transfer, has been observed only in captivity and uniquely among subjects educated in experimental-language training. This is the case with Sarah, studied by David Premack

(Premack & Woodruff 1978; Byrne 1995, 84–85), in the particular context of spatial competence.

The lack of inventiveness of chimpanzees could be explained as an absence or only minor development of their long-term memory. However, it is true that researchers have mostly studied the phenomenon of working-memory recognition, whereas studies concerning the recall of long-term memory have been neglected. This is perhaps because the latter is considered to be exclusively linked with linguistic information and thus inaccessible in the study of species lacking language (Vauclair 1992, 106). The only case of this type yet studied is that of Sarah.

If apes do have access to information stored in the long-term memory, their lack of “inventiveness” could be due to a lack of need for it in their natural environment, or a lack of social motivation. The chimpanzee Sultan, studied by Köhler, showed analogical reasoning. However, this remains an isolated and individual case and he did not transmit it to other members of the group (Köhler 1925). In other words, these aptitudes do not occur in nature because there is a lack of need or a lack of social connections between individuals.

*When did analogical reasoning first appear among the hominins or first humans?*

The degree of complexity required to realize a biface implies the capacity to preview and plan certain operational stages. It is obvious that working memory is not sufficient here and the recovery of long-term memory is necessary. We can thus conclude that *Homo erectus* was able to perform analogical reasoning.

Before this time, we can consider that the realization of choppers or chopping tools might depend only on the working memory. The capacity of this memory is weak – implying no more than  $7 \pm 2$  units – and rapidly forgotten, in about 20 seconds, but it is sufficient to realize a cutting edge.

Meanwhile, the invention of stone knapping itself results from the technical transfer of an action to a different material. The percussion movement used to crack bone or hard fruit could have led to the use of percussion to obtain a cutting flake (de Beaune 2000, 176–179). This invention could have occurred in three stages.

The first stage corresponds to the use of cobbles or blocks to crack bones, hard fruits, or wood. An accidental flake is produced. The author of the

action can store it – or not – to use it. This attitude, observed among modern chimpanzees, could have occurred among Australopithecines.

In the second stage, similar actions are employed but now the user focuses on accidental debris. Flakes serve as knives or scrapers to cut, scrape, slice, or saw animal or vegetable materials.

Though chimpanzees rarely act in this way, it is probable that the earliest Australopithecines used such flakes to scrape the buried parts of plants, for example. Among the activities that could have accidentally produced flakes, we can consider nut cracking, which is performed by some chimpanzees, or the cutting up of carcasses, unknown by chimpanzees, but perhaps practiced by some Australopithecines.

In the third stage, the deliberate will to produce flakes by knapping a cobble with a hammerstone appears. The hammerstone thus becomes a basic tool that serves to produce flakes from a block or nodule, which is now transformed into a core. The artisans are now interested not only in the intentionally produced flakes, but also in the cobble or block with a sinuous edge on one of its extremities and a blunt surface for holding on the other. These are choppers. The most recent Australopithecines, *Paranthropus*, or the first humans were certainly the first actors in this third stage.

Marchant and McGrew have recently proposed a similar hypothesis (Marchant & McGrew 2005). If we accept such a scenario, we must admit that these first knapping tools provide some evidence for the capacity for analogical reasoning, but we do not yet know who among these first hominins possessed this capacity.

### **Invention processes: The neurological perspective**

These data concerning the link between neuronal evolution and the evolution of cognitive capacities are contradictory. All researchers recognize that brain growth during hominization, which is shown by an increase in the thickness of the cerebral crust and in the size and ramification of neurons, would have led to a greater richness in the interneuronal connections, which itself would have led to a significant improvement in cognitive capacities, as shown in Figure 2.1 (also see Changeux 2000, 196).

The figure shows the topography of the meningeal vessels on the parietal bone of some hominins. This regulatory system, which is physiologically very important, is linked to the effective functioning of the brain. Known through endocranial casts, it shows a gradual increase in complexity during

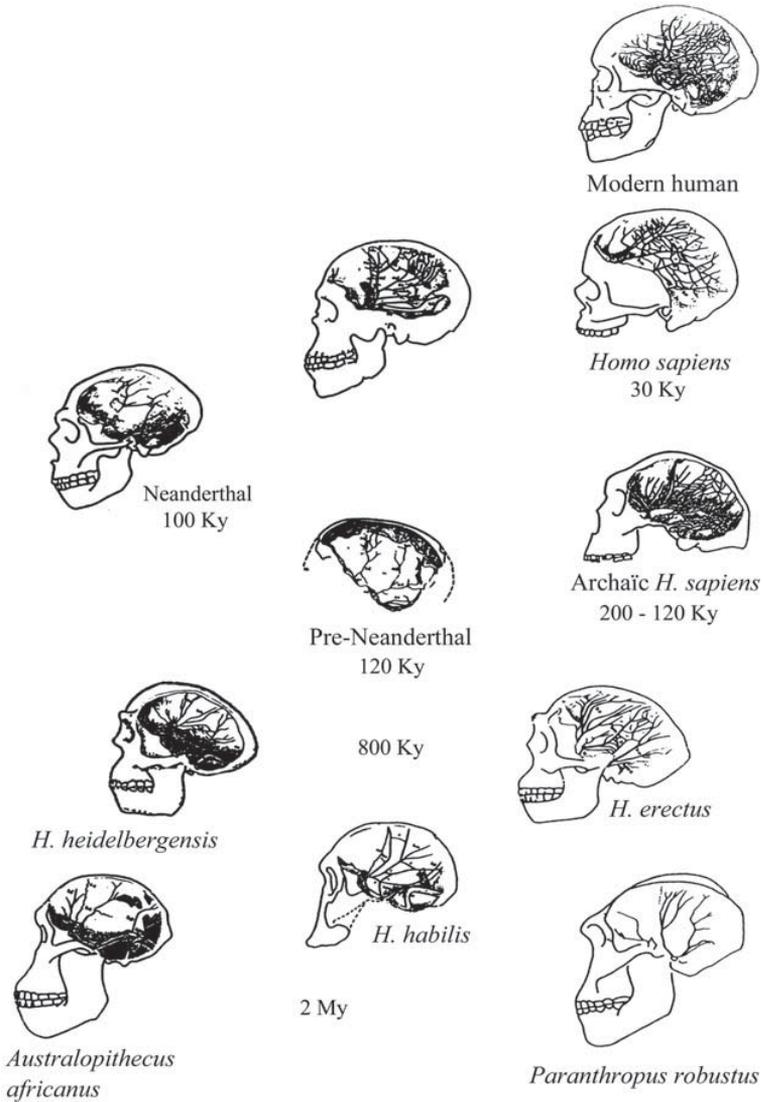


FIGURE 2.1. Topography of the meningeal vessels on the parietal bone of some hominins, adapted from Saban (1995). The possible filiations and hybridizations indicated by Saban by continuous or dashed lines are now outdated. (Courtesy of Elsevier Masson.)

hominization. This topography was compared by Saban with those of young modern children during their development. It is remarkable to observe that the topography of the meningeal vessels of *Paranthropus robustus* (cranial capacity: 520 cc) resembles that of a modern newborn; that the distribution of the vessels of early humans (*Homo habilis*, cranial capacity: 700 cc) is close to that of a 40-day-old modern child, and that of *Homo erectus* from Java (cranial capacity: 1,000 cc) resembles that of a 1-year-old modern child.

Moreover, researchers agree that brain growth primarily concerns the neocortex, and, more precisely, the frontal lobe, which is very important in human beings because it represents nearly one third of the cerebral volume. This aspect developed considerably during hominization, the earlier hominins having a supraorbital torus that blocked the development of the skullcap above the forehead.

But here is where the unanimity of opinion stops. For a precise understanding of the link between human cognitive capacities and cerebral organization, there exist two main, and rival, theses: localizationism and connectionism.

### *Localizationism*

Supporters of localizationism, known as localizationists, suppose the existence of a correlation between mental functions and specific areas of the brain. Arising at the beginning of the nineteenth century, this theory was greatly developed following the creation of a cerebral map. More recent cerebral imagery seems to point in the same direction.

The frontal lobe, which is of specific interest to us here because it is the one that developed the most during hominization, seems to be the center of reflexive conscience and upper psychism. It is here that intentions seem to arise and where programming, initialization, and control of voluntary behaviors seem to occur. In any case, researchers agree that certain complex apprenticeships, such as the solving of algebraic equations, multiple language learning, or motor abilities, take place in the prefrontal associative zones.

Moreover, analysis by positron emission tomography has been used to examine brain activation during experimental stone toolmaking (Stout et al. 2000). Experiments show that the main areas activated by an experienced modern knapper (neocortex and cerebellum) are exactly those that

underwent the greatest expansion in hominid evolution. Therefore, some palaeoanthropologists are certain that the enlargement of the frontal lobe during hominization is related to cognitive abilities and language (e.g., Bradshaw 1997; Gärdenfors 2004).

Many neurophysiologists remain skeptical, however, concerning an excessive localizationism. Renowned French surgeon and anthropologist Paul Broca himself pointed out that a functional deficit resulting from the deterioration of a specific area, far from providing evidence for the role of that area, could also prove that a nervous circuit removed from the actual center of the function involved had been interrupted (Cocude & Jouhaneau 1993, 411).

### *Connectionism*

This brings us to the second thesis: connectionism. According to this theory, the cortex would be organized according to a certain homogeneity based on the notion of a nervous system network: modular units would be interconnected with a similar structure and function. In other words, different functions would be assumed by particular cortical areas, but largely distributed among the cerebral tissue. Each cortical area would thus be more or less implicated in different functions.

Long-term memory, for example, does not seem to have a precise localization and appears to be registered at the level of synaptic connections in both hemispheres with no precise anchoring. Each event would thus be stored at a large number of points in the form of traces dispersed throughout the brain (Cocude & Jouhaneau 1993, 407).

The brain would act statistically, each cerebral area participating in all the mental operations, but with varying degrees of implication according to the operations (E. R. John, cited by Cocude & Jouhaneau 1993, 411). This supposes a weak functional specialization of cortical neurons and tremendous brain plasticity, which could explain the apprenticeship ability and modification faculty dependent on experience. Plasticity also explains why a function that was previously assumed by a destroyed area could be taken over by another area (adjoining or homologous in the other hemisphere) after a lesion at a particular point. At the neuronal level, this would be reflected by a biochemical modification corresponding to mnemonic traces left by experience and liable to be patterned again.

In addition, neuronal circuits are not unique, but redundant, thousands of cells having identical tasks in parallel. The best proof of this redundancy is that the daily death of many neurons that are never replaced does not result in any apparent malfunction. This shows that the same memory is coded in many parts of the cortex and not localized in a unique network.

*A compromise between localizationism and connectionism?*

How then can we explain the observation that certain lesions seem to correspond to particular areas, which are also visible through cerebral imagery? It is possible that the two explanations – localizationism and connectionism – are not necessarily contradictory. Lambert was of this opinion: “Plasticity involves a balance between stability and further modeling, if not, without invariants, the brain would always be destructured and memory of an extreme lability” (Lambert 2006, 52). Moreover, Lambert and Rezsöházy show that this plasticity is not limited to synaptic plasticity but rather concerns many biological domains, emphasizing the astonishing coexistence between “a coherence that is maintained and a correlative ability to distort itself in order to adapt to conditions that are susceptible to change” (Lambert & Rezsöházy 2004, 287).

In addition, cerebral plasticity seems to be more developed during infancy when a child is in the process of development and the neurons and synapses are being organized. Adult plasticity diminishes as a result of the number of acquisitions they already have (Bradshaw 1997). This explains why children recover and compensate more easily and more quickly than adults in the case of cerebral lesions.

Therefore, the two theses would be viable. As Changeux suggests, “Functional specialization of cortical areas indeed exist . . . but these areas are very largely interconnected. They can group in very large and much more global functional units” (Changeux 2000, 49).

Although all cerebral areas can be concerned by a particular cerebral activity, there exists a certain hierarchy: the more sensory objects concern abstract and general concepts, behavior rules, and relations between oneself and others, the more the contribution of the frontal and prefrontal areas becomes important. Concrete images mobilize essentially sensorial primary and secondary areas when concepts have a larger connectivity. The increase in the hierarchy from the perceptual to the conceptual is accompanied by a progressive mobilization of primary somatosensory cortex,

association cortex, and prefrontal areas. There thus exists a sort of geography of comprehension in our cerebral cortex (Changeux 2000, 115).

Returning to hominization and the evolution of the neuronal capacities of humans over thousands of years, we can propose some preliminary conclusions.

1. If cognitive abilities are in fact localized, we must admit that an enlargement of the frontal lobe plays a prominent role in psychic, cultural, and technical human evolution, probably by allowing humans to innovate and adapt their knowledge. Whereas long-term memory seems to concern whole cortex territories, the short-term or working memory seems closely related to the frontal cortex. However, we see that the latter is essential to analogical reasoning.
2. Although the brain is highly plastic and possesses significant capacities for self-modification, we have seen that this adaptive function would be related to the neuronal networks that follow variable paths. However, the larger the cortical surface, the more numerous are the networks. The cortical surface of cerebral circumvolutions is much larger in humans than in other hominids (64% of the cortical surface is hidden in the cerebral recesses, versus only 7% for primitive monkeys). Therefore, even without information concerning the precise localization of cerebral abilities, we can conclude that the exponential increase of hominin brain volume must be related to the increase of cognitive abilities.
3. If a comprehension geography indeed exists in the cortex, with a hierarchy from the perceptual to the conceptual, we saw that prefrontal areas are in this case implied in the most abstract operations and those concerning relations between oneself and the other; this point confirms the link between the increase of the prefrontal cortex and abstraction or planning operations, or, in other words, the analogical reasoning conditions that permit technical invention.

## Conclusion

What can we conclude from this confrontation of different disciplines? I would be tempted to link the three phenomena exposed at the beginning of this chapter: first, there is an exponential frequency and increasing complexity of the toolkit and other productions, material or not; second,

the analogical reasoning process appeared as early as the beginnings of hominization; and third, the development of the cortical surface and pre-frontal cortex involving mnemonic traces favors stocking, which permits the analogical reasoning that could lead to invention.

Though this parallelism could seem commonplace, it shows that the conditions of technical invention were present much earlier than we could have imagined a priori: as early as the appearance of the first knapped-stone tools. Furthermore, though technical inventions seem to increase and diversify according to an exponential rhythm during prehistory, it is possible that this is not due to an improvement of neuronal or cognitive conditions already acquired but to external circumstances such as a greater population size, which would have increased the probability of meetings between two ideas or two techniques.

The investigations of Stanislas Dehaene (cognitive neuroimaging specialist) concerning the neurological processes employed during reading apprenticeship seem to point in nearly the same direction, showing that neurophysiologic constraints could play an important role during the birth of cultural inventions. These inventions would be adopted only when they invade cerebral areas initially devoted to sufficiently similar functions. This means that “the cultural variations that mankind can produce are not unlimited” and “are strictly constrained by representations and cerebral mechanisms inherited from evolution and which define our human nature” (Dehaene 2003, 198). In this way, the instantaneous success, or, in contrast, the difficult apprenticeship, of a cultural object could be explained by its greater or lesser appropriateness with the representations shaped by our brain. We rejoin here the idea of exaptation developed by Stephen Jay Gould.

## CHAPTER 3

### Innovation and creativity: A neuropsychological perspective

*Andreas Kyriacou*

The archaeological record suggests that stone tool manufacture was fairly stable throughout much of the Palaeolithic period. For 1.5 million years, only limited technological innovation seems to have occurred. Some researchers propose that innovation remained gradual throughout the entire Palaeolithic (McBrearty & Brooks 2000). However, many regard the more elaborate forms of manufacturing found in southern Africa and dated to around 80,000 to 70,000 years as an important milestone in human evolution, marking the transition from the Middle to the Upper Palaeolithic (Wurz 2002). At Howiesons Poort, small blades were found that are believed to have been hafted to form composite tools, and raw materials were imported from distant sources (Minichillo 2006). Clearly intentional ornamental work was also found at the Blombos Cave (Henshilwood et al. 2002). In Europe, a similar shift took place around 43,000 to 35,000 years ago. It is believed that these advancements in toolmaking, including the increase in stylistic features and the creation of explicitly decorative items, coincided with a rise in population densities; an increased sophistication of the procurement of raw materials, including long-distance trading; the emergence of musical instruments; and possibly the first burial sites (see Mellars, 2002 for a distinction of 12 features reflecting this transition). Clearly, such advancements wouldn't have been possible without suitably equipped brains. In this chapter, the evolution of one crucial cognitive capacity is explored: our species' amazing ability to innovate.

One doubtlessly crucial factor was the continuous increase of brain size from approximately 400 cc in early hominids to 1,350 cc in *Homo sapiens* – which is partially mirrored by the continuous increase in stature

from an estimated 125 cm to that of modern humans (for a comprehensive overview of data on hominid cranial capacities and body sizes, see Collard 2002). As imprints on the inner surfaces of skulls and fossilized endocranial casts show, the increase in brain size was paralleled by a general closure and tightness of the spaces interposing the main cortical lobes (Saban 1995; Bruner 2003). Importantly, the neocortex expanded to a much greater degree than more ancient brain structures. Evidence for an increase in size of frontal areas has been found in *Australopithecus*, whereas posterior areas underwent a gradual change much more recently (Falk et al. 2000).

Unfortunately, data of cranial morphology alone cannot explain the cognitive capacities that the bearers of the respective brains were equipped with. We can, however, look at the brains of current-day humans to see what has evolved. Regarding brains, we have not only a profound understanding of anatomical features down to the cellular level, but also an increasing insight into their functioning. We can monitor creative behavior in the laboratory and detect neural activation by using brain-imaging techniques. Furthermore, we have verbal protocols of creators of recent inventions. Their introspective observations help us to understand the process of innovation in more naturalistic settings.

Let us first look at what some world-famous creative thinkers and innovators had to say about what made them outstanding. Albert Einstein argued that “combinatory play seems to be the essential feature in productive thought” (West 1997, p. 26). French mathematician Henri Poincaré opined that “among chosen combinations the most fertile will often be those formed of elements from domains which are far apart” (Ochse 1990, p. 210).

For Einstein and Poincaré and many others who reflected on their own innovative thinking, the association or blending of existing distinct and seemingly unrelated concepts is thus pivotal to creative thinking. It is by no means only theoreticians in the fields of physics or mathematics who are famous for such combinatory achievement. Johannes Gutenberg is said to have developed the printing press with moveable type by combining the preexisting technology of the wine press with that of the coin punch (Man 2002; but see Adams 1991, for evidence of forerunner innovations and de Beaune, this volume, for prehistoric examples).

Various creativity techniques are based precisely on this idea of linking previously unrelated ideas. To identify such novel combinations, the

Swiss-American astrophysicist Fritz Zwicky suggested starting with defining a problem space by deciding on relevant properties that could be manipulated. For a physical object, these may be attributes such as size, shape, and texture. Subsequently, for every property a set of possible values is derived from existing examples. Finally, the innovative properties are assessed for every cell in the so created  $n$ -dimensional space. Those combinations that are novel and useful are those of interest. Zwicky himself applied his method of “morphological analysis” to such diverse fields as the classification of astrophysical objects, the development of propulsion systems, and the legal aspects of space travel and colonization (Ritchey 2008), thus substantiating a claim he made in the 1948 Halley Lecture to fellow astronomers: “The morphologist for the solution of his problem will trespass into many fields.” Other techniques use random elements, such as a word picked from a dictionary, to trigger novel and potentially useful associations with an object of interest.

### Divergent and convergent thinking – core processes of creativity

Both the historical examples as well as these creativity techniques map nicely onto definitions of creativity that were proposed in the middle of the last century when creative thinking became an increasingly popular research subject of its own. Mednick (1962) proposed the following definition: “The forming of associative elements into new combinations which either meet specified requirements or are in some way useful.” For Mednick, creative thinking thus consists of two distinct subprocesses, that is, the generation of novel ideas and their evaluation in a given context. Guilford (1950) had already differentiated between divergent and convergent thinking. The former describes the generation of novel ideas; the latter describes the ability to bring together information to solve a particular problem.

This disentangling of creative processes allows researchers to surmount the methodological constraints of introspective reports. In a laboratory setting, tasks can be designed to assess divergent or convergent thinking selectively and neuroimaging techniques can reveal the areas of the brain in which neural networks are recruited during these processes.

Divergent thinking tasks are frequently designed in such a way that there is no predefined number of possible solutions. A well-established test is the Unusual Uses Task (Torrance 1966; Guilford et al. 1978), in which

participants are requested to think of unusual uses for a common object such as a brick or a cardboard box.<sup>1</sup> Answers can be assessed with respect to fluency (the number of uses given), cognitive flexibility (the number of different types of uses, e.g., using a cardboard box as a container versus as a platform), and originality (the infrequency of a suggested solution). Such ratings can be compared with personality traits, and there are findings that suggest that divergent thinking correlates with openness to experience (McCrae 1987) but also with psychoticism (Woody & Claridge 1977; Leonard & Brugger 1998).

Mednick's (1958) Remote Associates Test is frequently used to assess convergent thinking. Participants are given three words that have no obvious relationship, such as *board*, *magic*, and *death*. The task is to find a fourth word for which a link to every one of the given items can be made (solution: *black*). The task involves an initial phase of divergent thinking during which possible solutions are generated. These candidate items then have to be checked against the task requirement. This is the convergent thinking phase. Naturally, the solving of such a problem typically involves iterations of divergent and convergent thinking, as initial suggestions will often have to be discarded.

### Neurobiology of creativity

Brain activity of individuals accomplishing tasks such as the Unusual Uses or the Remote Associates Test can be observed. Two types of design are frequently used: The comparison in activation patterns between creative and noncreative tasks or between highly and less creative individuals. Carlsson et al. (2000) measured changes in regional cerebral blood flow using an inhaled weak radioactive tracer to determine which areas of the brain were more active during the Unusual Uses Task than during a rest state. They recruited two groups of participants who had been selected from a larger sample because of their scores at either extreme on a creativity scale. Both the low- and the high-creativity group showed increased frontal activity

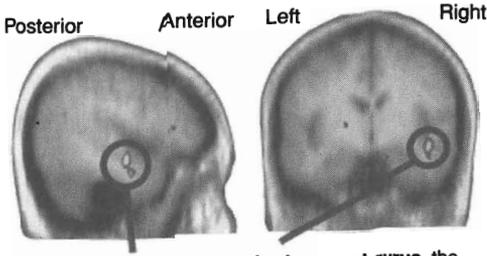
<sup>1</sup> It should be stressed at this point that early hominid creativity was surely strongly grounded in the material world, and interacting with a physical object is not fully on par with thinking about its use. Unfortunately, neuropsychological laboratory tests tend to isolate participants from the material environment, in part for practical reasons: body movements pose considerable design challenges to neuroimaging studies.

while generating ideas for the use of a brick. However, the highly creative group showed bilateral activation, whereas activation was confined to the left hemisphere in the less creative group.

Using functional magnetic resonance imaging, Howard-Jones et al. (2005) found a pronounced increase in right frontal neural activity during a divergent thinking task in which participants were asked to generate stories from sets of three words. Half of these word triplets were semantically related (*magician, trick, rabbit*). In the other sets, the words bore no obvious relation to each other (e.g., *flea, sing, sword*). In addition, participants were asked to either be creative or be noncreative in their plot generation. The stories were later assessed for creativity by external examiners. Nonobviously related stimuli and the instruction to be creative both enhanced creativity ratings. Functional magnetic resonance imaging measurements revealed that neural clusters in the middle frontal gyrus of the right hemisphere showed highest activation when participants were asked to invent creative stories based on nonrelated words.

Other findings suggest that neural clusters in the right hemisphere are not only crucially involved in divergent thinking, but also in convergent thinking. Jung-Beeman et al. (2004) used the Remote Associates Test in conjunction with functional magnetic resonance imaging and electroencephalography in the search of neural correlates of insight. Problems such as those posed by the Remote Associates Test frequently trigger a “eureka moment” when participants find the correct solution. The researchers compared the signals of those items for which participants perceived such a moment of insight with those items for which this subjective feeling did not occur. Differences between the two conditions were most pronounced in the right anterior superior temporal gyrus, which is a fold in the upper part of the temporal lobe. Insight solutions led to significantly higher neural activation in this area than noninsight solutions (Figure 3.1).

From their data, Jung-Beeman et al. concluded that this did not reflect an emotional response to having found a solution, as the same area was also activated early in the problem-solving process. Thus, the right anterior superior temporal gyrus seems to be involved in both early problem evaluation as well as solution detection. The researchers stressed that the result was unlikely to be an effect of greater task difficulty, as response times to insight solutions were not greater than to those items that were solved without triggering a eureka experience.



The **right anterior superior temporal gyrus**, the area with the greatest difference in signal change between insight and non-insight problems - see chart on the right

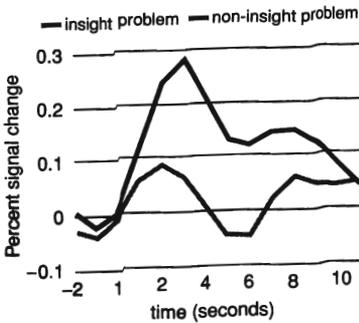


FIGURE 3.1. Increase of neural activation in the right anterior superior temporal gyrus during so-called eureka moments. (Source: Jung-Beeman et al. 2004, by permission of Mark Jung-Beeman and PLOS Biology.)

### *Hemispheric specialization*

The fact that these tests predominantly trigger networks located in the right side of the brain confirms what has been known in neuropsychology for well over a century: The two hemispheres have undergone different forms of specialization. Ever since Broca and Wernicke made a link between lesions in the left side of the brain and linguistic impairments, language processing has figured as the most prominent example of such functional asymmetry. Numerous other cognitive abilities have also been found to be implemented asymmetrically in the brain. Well-established areas are the processing of visuospatial information, emotions, olfaction, and attention (for a comprehensive overview on brain asymmetry in several species, see Hellige 1993).

An increasing body of evidence also suggests that the two hemispheres have adopted different strategies to meaningfully integrate novel information. Using a lateralized tachistoscopic design, Rodel et al. (1992)

demonstrated that participants recognized links between semantically closely related word pairs (*fruit–apple*) more easily if these were presented to the left hemisphere, via the right visual field. For semantically more distantly related concepts (*sleep–death*), however, performance was better when the stimuli were displayed in the left visual field, and hence projected to the right hemisphere. Similarly, Kiefer et al. (1998) found that in a primed lexical decision task, effects of semantically distant primes could only be observed in the right hemisphere. In such tasks, real or pronounceable nonsense words that obey orthographic rules are presented to either side of a participant's visual field at an angle that ensures that the retinal image of the stimulus is projected only to the contralateral hemisphere. The task is to state whether the presented word is a real one or not by pressing a matching button. For most individuals, responses to stimuli presented to the right side are processed with higher accuracy and speed, as the language-dominant left hemisphere receives the signal directly from its own visual cortex.

Lateral differences in electrophysiological responses to linguistic testing material have also been observed. Federmeier and Kutas (1999) made subjects read sentences for which the last word belonged to one of three categories: the expected word, an unexpected word of the same semantic category as the expected word, or a word of an unexpected category (“The knight in shining armour drew his sword/ blade/pay”). Using electroencephalography, the researchers analyzed the so-called N400 response, a negative deflection in voltage at around 400 ms after stimulus presentation, which has been established as a reliable marker of a surprise reaction. The researchers found that N400 signals were larger for words of an unexpected category than for unexpected words of an expected category in the left, but not in the right hemisphere. Federmeier and Kutas concluded that the left hemisphere's processing of context is predictive whereas the right hemisphere's processing is integrative. Ramachandran (1995) suggested that the strikingly different abilities of the two hemispheres to accommodate novel information may partially account for the rare condition of anosognosia of hemiplegia: Patients with parietal strokes may suffer from paralysis of the opposite body half if their motor cortex is affected. Remarkably, some of these individuals remain unaware of their condition – even if they are unable to walk or perform bimanual tasks such as tying a shoelace. However, this inability to update one's own body schema occurs almost exclusively after a right-hemispheric stroke. Ramachandran concluded that, in the healthy brain, “the left hemisphere ordinarily deals with small, local

anomalies by trying to impose consistency but when the anomaly exceeds threshold, an interaction with the right hemisphere forces a ‘paradigm shift’” (Ramachandran 1995, p. 40).

These results all support the hypothesis of Chiarello et al. (1990) that the left hemisphere only activates concepts that appear relevant in a specific context, whereas the right hemisphere makes a broader range of semantic links available, even if they do not seem to fit the current linguistic context. The right hemisphere thus seems superior in building new links between concepts and events. Naturally, the two hemispheres do not act in isolation. The corpus callosum, with its more than 200 million projections, by far the largest fiber bundle in the brain, as well as subcortical commissures, link the two hemispheres; input from the sensory organs is quickly forwarded to a multitude of cortical areas on both sides of the brain (for an overview of interhemispheric processing, see Banich 1995).

### *Distorted interhemispheric processing – the cause of madness and genius?*

The specialization of the two hemispheres may not just be advantageous, but inevitable for a normal functioning of the brain. Crow (1997a, 2004) suggested that a failure to develop hemispheric dominance for language could be the underlying cause of schizophrenia. Reduced functional asymmetry seems paralleled by reduced anatomical asymmetry. Brains of healthy individuals show a slight rightward frontal and leftward occipital torque. Some patients suffering from schizophrenia have been found to have reduced or even inverted torques, although not all comparisons between brains of healthy and schizophrenic individuals have shown significant differences (Mackay et al. 2003; Narr et al. 2007), and administration of neuroleptics has been found to restore regular asymmetry patterns (for an overview see Mohr et al. 2005). Berlín et al. (2003) proposed that what they labeled as “temporal” and “spatial” aspects of language are processed in opposing hemispheres and rely on a precise tuning of interhemispheric transmission. In their model, temporal sequencing of speech is accomplished by the language-dominant (usually left) hemisphere. Such a constructed sequence accesses neural traces of semantic contents through commissural fibers at multiple sites in the nondominant hemisphere. Other researchers have proposed that right frontal areas are only recruited when semantic ambiguities have to be resolved (Stowe et al. 1998). An imbalance

in this interplay between the hemispheres may result in the symptoms that are typical of schizophrenia: disordered thought, hallucinations, and delusions.

Distortions in interhemispheric processing have furthermore been suggested as the cause for schizophrenia-like thought patterns in healthy individuals. Participants in a lateralized lexical decision task, who had declared above-average agreement belief in and experience with paranormal phenomena according to the Magical Ideation Questionnaire (Eckblad & Chapman 1983), showed levels of left-hemispheric activation similar to those of more sceptical subjects (Leonhard & Brugger 1998). However, for the “believers” an enhanced contribution of the right hemisphere was measured. Furthermore, in an experiment designed by Pizzagalli et al. (2001), participants were presented direct (*tiger* → *lion*), indirect (*lion* → *stripe*), or semantically unrelated primes before target items, for which they had to decide whether they were true words. Indirect primes presented to the right visual fields led to significantly shorter reaction times by believers, suggesting that this loosening of associations was again caused by an overly active right hemisphere.

On the basis of their own studies and previous findings, Leonhard and Brugger (1998) concluded that this behavior resulted from a lack of inhibition of right-hemispheric processing by the left hemisphere. As it has been shown herein, increased right-hemispheric processing also, however, seems crucial for creative idea generation. Conversely, left-hemispheric inhibition on right-hemispheric functions is a major obstacle to high creativity (Bogen & Bogen 1969). This question arises: If – as Crow (1997b) formulated it – schizophrenia is the price that *Homo sapiens* pays for language, then is creativity its prize? The argument seems reasonable: Advanced symbolic processing necessitates specialized areas and these have evolved predominantly in the left hemisphere. The right hemisphere makes use of the availability of symbolic representations of real-world objects and abstract concepts, and it seeks to link them in novel ways. (It is open to debate whether such advancements in symbolic processing required fully developed linguistic skills as we find them in current-day humans.)

Many researchers have investigated the links between psychotic disorders and creativity (for a recent review see Barrantes-Vidal 2004). Numerous studies have indeed postulated a relationship, but findings are far from conclusive; one possible reason for this is that very different measures of creativity have been used by different researchers (Weinstein & Graves 2001).

Kyriacou and Brugger used the Word Halo Test (Armstrong & McConaghy 1977) and the Remote Associates Test to measure both divergent and convergent thinking in the same participants. In the Word Halo Test, subjects are given a target word and five near-synonyms. They are asked to mark those words that they perceive as being equal or almost equal in meaning to the target, like this: “*great – huge, worldwide, infinite, precious, intense.*” Any choice from zero to all five items is possible. Kyriacou and Brugger also used the Magical Ideation Questionnaire to measure the degree of schizotypal thinking and revealed a double dissociation: Persons with a sceptical attitude toward paranormal phenomena accepted fewer synonyms in the Word Halo Test than the believers. In the Remote Associates Test, however, the sceptics outperformed the other group.

The results suggest that the link between psychosis and creativity is not as straightforward as it has sometimes been proposed. The dissociation also explains the Janusian face of magical ideation: On the one hand, pronounced divergent thinking allows one to “see” connections between loosely associated concepts; on the other hand, poor convergent thinking may prevent the integration of novel ideas into an established body of knowledge and thus foster idiosyncratic, delusion-like beliefs. In some cases then, as the American science fiction writer Thomas M. Disch suggested, creativity equals “the ability to see relationships where none exist” (Segal 2001, p. 32). Nevertheless, a tendency to overinterpret connections may well have been an adaptive strategy, as the creative advantage may outweigh the costs of being prone to misinterpreting the environment.

### **Aligning neuropsychology and palaeoneurology**

Functional hemispheric specialization must have been a key feature of human speciation. The hemispheres of the *Homo sapiens* brain also differ anatomically. It is parsimonious to suggest that anatomical and functional asymmetries are causally linked. Traces of evolving hemisphericity have indeed been found in the fossil record (Holloway 1995). Furthermore, palaeoneurology is offering more general models of cerebral evolution in humans (Weaver 2002). Similarly, a variety of frameworks attempt to explain human cognitive development. Unfortunately, there is limited agreement with regard to the order and time scale of cognitive developments on the one hand and the evolutionary driving forces on the other hand. Further insight will likely come from a close cooperation of the fields.

## CHAPTER 4

# The archaeology of consciousness

*Matt J. Rossano*

The compelling art, artifacts, and grave goods of Upper Palaeolithic hominins leave little doubt that their conscious experience was as rich and full as our own. Inferences about the conscious experience of earlier hominins are far more speculative. Fully human consciousness, however, did not arrive *ex nihilo* at the onset of the Upper Palaeolithic period. In this chapter, I pursue the evolving consciousness of Lower and Middle Palaeolithic hominins by following two lines of evidence in the archaeological record: (1) skill development in toolmaking that required conscious deliberate practice and (2) the controlled use of fire and the consciousness-altering rituals associated with fire that expanded human subjective awareness and working-memory capacity. According to Mithen's (1996) model of cognitive evolution, toolmaking represents technical intelligence, whereas rituals associated with fire represent social intelligence. Mithen contends that increasing cognitive fluidity among these (formerly) isolated forms of intelligence was the key to the modern human mind. This review argues that increasing consciousness may have been the mechanism that catalyzed this fluidity, which led ultimately to the florescence of symbolism in the Upper Palaeolithic.

### **Line 1: Toolmaking and the mind**

The cognitive abilities implied by various forms of hominin tool manufacture have been discussed and debated in numerous works (e.g., Wynn 1985; Gowlett 1992; Shick & Toth 1993; McPherron 2000). As an indicator of consciousness, toolmaking represents a particular skill or form of expertise. Could this skill have been acquired without conscious awareness?

Many forms of pattern recognition, rule abstraction, motor coordination, and associative learning can be acquired unconsciously (see Stadler & Frensch 1998; Dehaene 2001 for reviews). However, research on the limitations of unconscious learning indicates that when the sensory patterns that control motor responses are spatially or temporally extended, or when mental or motor operations must be combined in novel ways, then conscious awareness must be involved. Achieving expertise in skills that make these sorts of cognitive demands typically requires a process known as deliberate practice (Ericsson & Lehmann 1996; Ericsson 2002). Deliberate practice requires a level of conscious awareness that is vanishingly rare, if not nonexistent, among nonhuman animals (Rossano 2003).

Deliberate practice requires concentrated effort directed at improving specific mental and physical skills. It typically includes (1) evaluating one's skill state against a more skilled model, (2) directing effort consistently for the advancement, not just maintenance, of skill, and (3) exercising voluntary, flexible control over target behaviors. As an example, think of a person closely observing another person who is executing a proper tennis backhand and then attempting to replicate that motion by repeatedly hitting a ball against a backboard. Or, on a more strictly intellectual level, Charness et al. (1996) have shown that chess expertise requires countless hours studying the games of past masters, predicting their moves in various situations. Chess novices use their mistaken predictions as a means of training themselves to more accurately "see" and "think" as a grand master. Although many animals acquire complex motor skills and some even make tools, there is little if any evidence that animals hone skills by using deliberate practice (Donald 1993, 1999; Rossano 2003; Stout 2005). As Merlin Donald succinctly puts it, "Baboons throw projectiles in a fight, but they don't systematically practice and improve their throwing skill" (Donald 1993, 152).

### *Deliberate practice and toolmaking*

When did hominin tool manufacture require the systematic practice absent among other species and, therefore, evidence a level of conscious awareness that can be described as "unique?" The earliest stone tools, the Oldowan industry, appeared about 2.5 million years ago and consisted of small flakes broken from a core (Semaw et al. 1997). Although wild apes do not create Oldowan-type tools, captive apes have been taught to make approximations of such tools (Wright 1972; Toth et al. 1993). Most researchers agree that the

hominins who created Oldowan tools possessed a degree of motor control and timing that exceeded that of apes. This, however, did not represent a major intellectual advance (Toth 1985a; Wynn & McGrew 1989; Wynn 2002; see, however, Pelegrin 2005 and Chapter 9 of this volume). The same cannot be said of the later-emerging Acheulean industry (about 1.5 million years ago).

To many, the symmetry of some Acheulean handaxes represents an important intellectual milestone (Wynn 1981; Donald 1999; Suddendorf 1999, Wynn 2002). Unlike Oldowan tools, handaxe construction (especially later handaxes of about 0.5 million years) required considerable investment in time and energy, with toolmakers going through a series of flaking iterations before completing the final product. Wynn argues that late Acheulean handaxe makers, unlike their Oldowan counterparts, could not simply focus on the tool's edge, but instead had to understand how flakes trimmed from one part of the stone affected the tool's overall shape. Thus, knappers had to hold in mind multiple perspectives of the tool as it was being created, constantly adjusting their ongoing flake removal to meet the changing characteristics of the core as it was shaped (Bril et al. 2005; Pelegrin 2005). This process would therefore entail novel combinations of motor actions controlled by temporally and spatially extended sensory patterns. In other words, this skill most likely could not have been acquired or executed without conscious awareness.

### *Deliberate practice and the Acheulean handaxe*

The Acheulean handaxe is not an easy tool to make. Stephen Edwards, an experienced stone knapper, claims that many months of concerted effort would be required for one to reach the skill level of late Acheulean stone knappers (Edwards 2001, 606). Schick (1994, 584) enumerates some of the technical challenges facing novice handaxe makers. Common problems encountered by beginning knappers include the removal of too much width before the piece is adequately thinned, failure to maintain a good plane, poor control over the outline shape, failure to extend the bifacial edge through more obtuse areas of the blank, the removal of the tip end through uncontrolled flaking, or the breaking of the biface in half with too strong a blow.

Along with its technical complexities, this skill also requires physical strength, fine motor control, and sheer bravery (Schick & Toth 1993, 231,

237, 240). Schick and Toth (1993, 237) provide a vivid description of the hazards of handaxe making:

We know from experience that the injuries produced in quarrying massive flakes from boulder cores can be formidable, especially if one is scantily clad. We suspect that death due to loss of blood from a severed artery was probably not unknown in Acheulean times. Accidental injuries from flaking stone may have been one of the most common “occupational hazards” during these times.

Only *Homo* has mastered the handaxe. Evidence from contemporary stone knappers suggests that this skill could not have been acquired without deliberate practice. Among the few traditional societies where stone knapping is still present, years of apprenticeship are required for skill development. For example, stone knappers from Khambat (India) usually begin training at the age of 10 to 12 years and will spend anywhere from 3 to 10 years in apprenticeship (Bril et al. 2005; Roux & David 2005). Among the Kim-Yal of New Guinea, the craftsmen who produce stone handaxe-like implements (adzēs) are exclusively older males. Their apprenticeship begins at age 12 or 13 years, and 10 years or so is typically required to achieve the highest levels of adz-making skill (Stout 2005).

Note the following: Although implements made by these contemporary stone knappers are generally more complex than the handaxe, it is not unreasonable to assume that Acheulean handaxe makers would have required months to years of practice to perfect their skills. Evidence of this practice may be present in various forms in the archaeological record. These forms include (1) cores showing evidence of variable flake-removal techniques, (2) handaxes exhibiting variable levels of skill in production, and (3) ‘surplus’ handaxes potentially used as male-quality displays.<sup>1</sup> Each will be discussed in turn.

*Cores showing evidence of variable flake-removal techniques:* Bar Yosef (2006, 309–310) notes that discarded cores from many Middle Palaeolithic sites show an interesting temporal pattern of flake removal – the technique used to remove the last flakes is often different from the technique used to remove earlier ones. He speculates that (among other possibilities) old cores became substrates for skill acquisition. Youngsters may have used discarded

<sup>1</sup> Manuports may provide a fourth line of evidence for practice; this, however, would be throwing practice, which is not necessarily related to stone tool production and, therefore, will not be discussed. See Bingham (1999) or Corballis (2002, 79) for more.

cores to practice flake removal or a master may have used old cores to teach novices.

*Handaxes exhibiting variable levels of skill in production:* In her studies with modern handaxe makers, Winton (2005) has found that highly skilled knappers produce handaxes with a consistent proportional relationship between the tool's length and thickness. Among less skilled knappers, the length-to-thickness ratio is more variable. Assessing this ratio in ancient handaxes provides a potential measure of the artisan's skill level. Handaxes unearthed from the Lower and Middle Palaeolithic site of Dickett's Field, Holybourne, Hampshire (UK) have a generally consistent length-to-thickness ratio, whereas those from the Wolvercote site in Oxfordshire are more variable. This suggests that expert knappers predominated at the former site whereas a more variable range of skill levels was present at the latter (Winton 2005). A variable length-to-thickness ratio among a set of handaxes could very well indicate that knappers were working their way toward greater expertise.

*Surplus handaxes potentially used as male-quality displays:* At many handaxe sites, hundreds of handaxes show no evidence of use (Kohn & Mithen 1999; Klein & Edgar 2002, 107; Stringer & Andrews 2005, 225). Kohn and Mithen (1999) contend that handaxes may have served as a male-quality display. A male who could produce a high-quality handaxe may have been signaling his industriousness, competence, and overall mate quality (good genes) to local females. The hundreds of unused handaxes could indicate that male hominins were practicing handaxe-making skill. This interpretation fits nicely with the ethnographic evidence cited earlier from the Kim-Yal people, for whom adz making is the domain of mature males. Furthermore, these implements often carry symbolic and even sacred meaning as ritual exchange items and bride-wealth payments (Stout 2005).

### *Consciousness, toolmaking, and cognitive fluidity*

Mithen (1996) regards toolmaking as a form of technical intelligence that, according to his model, remained isolated from other forms of intelligence (e.g., natural history intelligence, social intelligence) throughout much of hominin evolution. The argument being advanced here is that the deliberate practice needed to acquire handaxe-making skill may have been an important mechanism behind increased cognitive fluidity. Constructing the handaxe required deliberate practice, which in turn required greater

conscious awareness. This heightened conscious awareness eroded the barriers between different forms of intelligence, especially technical and social intelligence. By around 300,000 years, this erosion is evident in a number ways.

First, more refined, regionally variant, and often aesthetically pleasing handaxes emerge in the archaeological record around this time (Shick & Toth 1993, 282–283). This suggests that the tool was now being appreciated as a social signal of one's skill and cultural identity (technical intelligence integrated with social intelligence). Second, it is around this time that both the Levallois technique for stone tool construction and the first evidence of composite tools emerges. Multistage tool manufacture and multiple component tools require the same kind of foresight, planning, and combinatorial or recursive thinking that are essential to language (Brooks et al. 2006). The very act of creating these tools (technical intelligence) may have required the ability to communicate about them (social intelligence). It is not surprising, then, that an advance in brain size and the emergence of two new species of *Homo* (*Homo neanderthalensis* and *Homo helmei*) occur at roughly this time as well (Ruff et al. 1997).

## Line 2: Fire, ritual, and expanding conscious experience

“It is really the beginning of humans. When you have fire, you have people sitting around the campfire together” (A. Brooks, as cited in Klein & Edgar 2002, 156). “Beyond being a tool, fire is a symbol . . . the only substance which humans can revive and kill at will. If there had been a trigger to arouse self consciousness and the ultimate sense of ‘otherness,’ it was fire” (A. Ronen, as cited in Klein & Edgar 2002, 156). Fire brings people together and provides a venue for social interaction and ritual behavior. Gatherings around fire not only build community, but alter and expand consciousness.

The evolution of human consciousness involved not just greater awareness, but an expanded range of conscious states. Fire, and the activities surrounding it, may very easily have played a critical role in the evolution of this expanded range of conscious states experienced by modern humans. Expanded and altered consciousness helped bring together social intelligence with natural history intelligence (knowledge of animal behavior and environments), thereby producing a supernaturalization of social life (Rossano 2007a). The natural world became another layer of the social

world as animal and natural spirits could be called upon through ritual to enhance individual and community well-being.

### *The control of fire and the beginnings of consciousness-altering rituals*

It is unclear exactly when hominins controlled fire. Some evidence suggests that it may have been as early as 1.4 million years (Brain & Sillen 1988; Belomo 1994), but this remains controversial (e.g., Binford & Ho 1985). By the Late Lower to Early Middle Palaeolithic, the evidence for the controlled use of fire is more convincing (Monnier et al. 1994; see also Klein & Edgar 2002, 156–157). By the Upper Palaeolithic, evidence for consciousness-altering shamanistic rituals appears (Lewis-Williams 2002; Winkelman 2002). It is unlikely that these rituals sprang forth fully formed in the Upper Palaeolithic, but instead emerged gradually from earlier Middle Palaeolithic behavior. Recent finds do, in fact, point to the presence of consciousness-altering rituals in the mid to later Middle Palaeolithic (Balter 2000; Hayden 2003, 108–115; Minkel 2006).

### *Rituals of focused attention*

If one traveled back in time 100,000 years or more and happened upon a group of our ancestors gathered around an evening campfire, it would hardly be surprising to find them singing, chanting, or just sitting mesmerized by the flickering flame. This manner of activity is so natural and commonplace that its importance is easily overlooked. Ethnographic evidence, however, indicates that rituals and celebrations around a central fire play a critical role in the community life of traditional peoples. Among the Kalahari !Kung, for example, campfire rituals such as healing dances, are essential to the life, health, and vitality of individuals and the community. A roughly biweekly occurrence, these dances are eagerly anticipated and practiced with relish (Katz 1982, 34–36). Although everyone participates in these dances, shamans are especially prominent. Through rhythmic dancing, they enter a trance state wherein they direct healing spiritual energy to those in need.

The prominent role that campfire rituals play in the lives of current hunter-gatherers suggests that this activity may have been important in our ancestral past as well. To have been sustained over many millennia, these rituals very likely offered some fitness advantage. McClenon (1997, 2002)

has marshaled considerable evidence indicating that those of our ancestors who were most susceptible to the beneficial physical and psychological effects of shamanistic healing rituals had a selective advantage over others in surviving illness or injury, overcoming debilitating emotional states, and enduring the rigors of childbirth. McClenon cites several converging lines of evidence to support his theory:

1. The universality (or near universality) of ritual healing practices across traditional societies (Winkelman 1990; see McClenon 2002, 67).
2. The fact that ritual healing consistently involves hypnotic processes and altered states of consciousness (see McClenon 2002, 67–71).
3. The evidence showing that hypnotizability, or the ability to achieve a mental state highly prone to suggestion, is measurable, variable, and has heritable components (Katz 1982, 138; also see Morgan 1973; Wilson & Barber 1978; and McClenon 2002, 93–96 for review).
4. The research indicating that ritual healing is often highly effective for a range of maladies in which psychological factors are involved, such as chronic pain, burns, bleeding, headaches, skin disorders, gastrointestinal disorders, and the discomforts and complications of childbirth (Katz 1982, 49–55; see McClenon 2002, 46–67 for review).
5. The evidence from comparative and archaeological studies indicating the existence of ritual, altered states of consciousness, and care of the sick among our primate cousins and hominin ancestors (Trinkaus 1983, 409–411; Goodall 1986; Lewis-Williams 2002; Hayden 2003).
6. The fact that the earliest medical texts (from Mesopotamian and Egyptian civilizations) closely connect healing with religious ritual (Majumdar 1975; Sigerist 1987 for review).
7. The research indicating that anomalous events associated with ritual, such as “miraculous” healing, are effective in inducing supernatural beliefs (see McClenon 2002, 70, 132–135, 150–151).

The potential antiquity of shamanistic rituals is further strengthened by evidence that neither sophisticated linguistic skills nor ideologies are needed for the rituals to be effective. It is the compelling nature of the ritual experience and not belief in a specific theology that is critical (e.g., a Muslim may find relief in a Christian-based healing practice as long as he or she accepts the power of the ritual itself; see McClenon 2002, 10, 79–83).

Furthermore, only minimal verbal expression is required (if at all) to add to the persuasive impact of the ritual (“relax,” “heal,” etc.). Indeed, part of the power of spiritual healing is that it is something beyond words and logic. Among the !Kung, ritual healing is caused by a powerful, mysterious spiritual energy call *n/um* (Katz 1982, 34). Thus, what is required for spiritual healing appears to be well within the behavioral and cognitive repertoire of our hominin ancestors: a belief in a healing spiritual power accessible through consciousness-altering ritual.

It is not hard to imagine that our *Homo sapiens* ancestors were engaging in campfire rituals of focused attention. At times, these rituals may only have involved group chanting, dancing, or hypnotic silence before the flames (the benefits of which should not be casually dismissed). At other times, they may have involved intensely dramatic shamanistic rituals in which soul flight, supernatural encounters, and so-called miraculous healings took place. More than likely, it was the immediate positive psychological effects (ecstatic emotions and social bonding) and physical effects (placebo-based health benefits, miraculous healings) of these rituals that provided the motivation for their enactment. However, over the long run, those whose brains were most ritually capable would also have been the ones to reap the greatest psychological and physical health benefits and, thus, fitness rewards.

### *Focused attention and enhanced working memory*

Recent neuroscience studies indicate that consciousness-altering meditative rituals activate and have long-term effects on the very areas of the brain that are critical to working memory and attention (Wallace, Benson, & Wilson 1971; Lazar et al. 2000, 2005; Newberg et al. 2001; Lutz et al. 2004; Carter et al. 2005). Coolidge and Wynn (2005; also see Wynn & Coolidge 2003, 2004) and Klein (1995) contend that a genetic mutation enhancing working-memory capacity provides the best explanation for the florescence of symbolism associated with the Upper Palaeolithic. Selection pressures brought about by the health enhancement of shamanistic healing rituals may provide a mechanism for the emergence and spread of just such a mutation (Rossano 2007b).

This modest, but significant, enhancement of memory may have been critical to the integration of social intelligence with natural history

intelligence that produced the supernatural layer of human social life. In explaining why the extraordinary cave art and symbolic artifacts of the Upper Palaeolithic were the exclusive domain of *Homo sapiens* and not Neanderthals, Lewis-Williams (2002, 190) has argued this very point: “Improved memory made possible the long-term recollection of dreams and visions and the construction of those recollections into a spiritual world.” Thus, unlike their Neanderthal counterparts, for Cro Magnons, an encounter with a bear during a dream or a trance could be recalled later and interpreted socially – the spirit of an ancestor offering strength and encouragement or warning of impending danger.

The interaction of campfire rituals and enhanced working memory created a powerful evolutionary feedback loop. Campfire rituals disproportionately enhanced the health of those whose brains permitted the deepest immersion into the rituals – and this, in turn, selected for brains with enhanced working-memory capacity. Brains with enhanced working-memory capacity could envision ever more compelling spiritual worlds whose power was accessible through campfire rituals, and so on. Enhanced working-memory capacity could very well have been a by-product of brain changes resulting from ritually induced health benefits.

## Summary

This chapter has followed two lines of evidence for evolving consciousness through the Middle Palaeolithic: (1) increasingly sophisticated tool manufacture requiring deliberate practice and (2) rituals of focused attention, centered on hearths, that altered and expanded conscious experience. According to Mithen, the modern mind emerged as greater integration took place among (formerly) isolated forms of intelligence. This review suggests consciousness may have been an important mechanism in achieving this integration. As the conscious demands of each of these intelligences increased, interaction with other forms of intelligence was facilitated.

Fully human consciousness did not materialize suddenly, or fully formed, with the so-called symbolic explosion of the Upper Palaeolithic. Evidence from the Middle Palaeolithic and earlier provides a sketchy but valuable prehistory of human consciousness. Human consciousness evolved along a number of separate but interrelated pathways – each contributing distinct, if somewhat overlapping, aspects to the full spectrum of our subjective awareness. The two lines discussed here are not the full

story. For example, there is increasing evidence that cooperative hunting among hominins may not have been possible without a deep understanding of another's mind (a theory of mind; see Mithen 1996, 168; Stiner 2006). Other important pathways wait to be identified and integrated into the emerging picture of the mind's past.

## Prehistoric handedness and prehistoric language

*Natalie T. Uomini*

The search for the origins of human uniqueness has often focused on laterality (see, e.g., Corballis 1989). In particular, lateralized language functioning in the brain and lateralized manual skill are thought to represent derived features of our lineage. Asymmetries of function are especially prominent in the everyday use of our hands, for which the most frequent pattern is for the left hand to act in a stabilizing role, whereas the right hand manipulates the object being held (Guiard 1987). The human-wide population-level bias toward right-handedness is often considered to distinguish us from the other great apes, but we lack information on the timing of its emergence.

Similarly, language is said to be a defining feature of our species. As another unique feature of humans, language falls within the remit of the cognitive abilities that make us human. The emergence of language has been studied in many different disciplines (linguistics, neuroscience, anthropology, psychology, and computer science, to name a few). However, the field that would appear the most relevant to language origins – the archaeology of human origins – has actually contributed very little data to the debates. Archaeology can provide indirect evidence for language by uncovering data on handedness in extinct hominins (Uomini 2006).

Right-handedness is said to be linked to language through a shared common substrate, located in the brain. This idea can be traced historically back to neurologist Paul Broca in the 1860s (Harris 1991), but is still current today.

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If the connection does exist, then any evidence for right-handedness in prehistory is evidence for language. Working within the framework of Guiard's (1987) bimanual model of handedness, this chapter reviews the evidence for hand-role differentiation in the archaeological and fossil records. Each potential marker has an underlying assumption about the biomechanical constraints that operate on the person doing the action. The review will assess these with facts of motor behavior and will subject several markers to experimental validation.

Special attention is paid to the earliest markers of laterality, which may contribute to the academic discussion about hominization, language origins, and cognitive evolution. The cognitive-archaeology approach that is now emerging is showing us that studying language and other aspects of cognition in extinct hominins must take into account the motor and perceptual skills that are embodied in prehistoric technology (Malafouris 2004; Haidle 2006a). Following de Beaune (2004), the earliest artifacts are considered to represent technologies that were probably already established prior to the earliest documented findings in the archaeological record. Therefore, evidence for right-biased hand-use patterns in materials such as the Kada Gona (Semaw 2000) lithics would indicate the latest possible date for the emergence of handedness. Unfortunately, none of those artifacts have been studied for handedness and the earliest potential markers date from the time of Acheulean technology, as will be subsequently discussed. First the bimanual model of handedness is described.

### Definition of handedness

In the context of human origins, the term *handedness* refers to our species-wide tendency (in statistically significant proportions) to assign consistent roles to the two hands, particularly in bimanual coordination. The commonly accepted proportion of right-handers is between 70% and 90% in populations around the world (Porac & Coren 1981; Annett 2002). Handedness thus refers to a group-level bias in hand-use patterns.

The evidence for hand use in nonhuman apes and other primates suggests that they do not display a population-level bias; however, many individual chimpanzees show task-specific hand preference (Fletcher & Weghorst 2005). Some studies even fail to find any significant hand preference at the individual level across tasks (e.g., Mosquera et al. 2007). Monkeys, in general, show no hand preferences except for complex tasks involving

tool use, but it is unclear what sort of bias exists among great apes (McGrew & Marchant 1992). From their meta-analyses of studies, McGrew and Marchant (1997) and Papademetriou et al. (2005) conclude that primates are individually lateralized, but do not reach the population-level rightward bias seen in humans. This unique feature of modern humans implies that handedness emerged from selective pressures sometime after the divergence from the ape–human common ancestor.

The characterization of handedness used here is adapted from Guiard's (1987) Kinematic Chain model of bimanual complementary role differentiation. This model is relevant to prehistoric activities, especially object manipulation and, more specifically, to tool manufacture and object prehension. The traditional definitions of handedness consider it as resulting from actions performed unimanually and tend to describe the right hand as "dominant." This is probably related to the traditional methods of measuring handedness in humans by questionnaires or by noting the writing hand (Oldfield 1971; Bryden 1977). In fact, this dominance can be seen as reflecting the greater speed, precision, and accuracy of the right hand in its role as manipulator. Often the stabilizing role of the left hand is ignored, despite its importance. An example is in handwriting, in which the left hand stabilizes the paper, actively moving it around, while the right hand manipulates the pen (Athènes et al. 2004). One common Palaeolithic task, scraping hides, which is often described as unimanual according to the hand that is holding the tool, also requires this coordination of both hands: one hand to hold and orient the hide, the other hand to manipulate the scraping tool. The degree of bimanual coordination for hide scraping is likely analogous to handwriting with pen and paper.

It is likely that most of the skilled activities taking place in the daily lives of prehistoric people required two-handed coordination, such as working wood and hide, bow shooting, digging, crafting bone and shell ornaments, painting, weaving, spinning, or threshing and grinding grain (Eshed et al. 2004). For example, knapping stone involves complex coordinated movements in both hands, with some degree of precision, spatial positioning, and timing necessary for both the right and left upper limbs. In a knapping event, the moment of contact between the hammer and the stone core results from a bimanually differentiated coordination of the core hand and arm with the hammer hand and arm (Stout 2003; Bril et al. 2005; Pelegrin 2005). This kind of coordinated bimanual action, with well-specified roles for each upper limb, can be said to characterize prehistoric object

manipulation. Therefore, a useful model will be one that accounts for the actions of both hands rather than focusing only on a single so-called dominant hand.

In the Guiard (1987) model of handedness, one hand (or arm, or both) performs movements that are qualified as high frequency, being more spatially and temporally precise (i.e., being faster and having a narrower target), whereas the other upper limb is low frequency, acting as a stabilizer or support, maintaining the spatial or temporal structure. To define the group-level handedness that is specific to humans, Guiard (1987) suggested that most humans tend to learn the low-frequency role with the left hand and the high-frequency component with the right hand. The model is endorsed by Hinckley's experiments (Hinckley 1996; Hinckley et al. 1997). He showed that subjects maintained the stabilizing role of the left hand and the manipulative role of the right hand even when the test objects were switched to opposite hands. The following review of archaeological data investigates whether these roles were also maintained throughout prehistory.

In the following review, the term *right-handed* will refer to a bimanual configuration in which the right hand is responsible for the finer component of the action, such as manipulating the tool, while the left hand takes on the coarser component such as holding the object being worked on. For unimanual actions, the hand executing the action is taken to be the dominant hand.

### Fossil and archaeological evidence for handedness

The archaeological data subsequently reviewed here include actions requiring complementary bimanual coordination and actions in which the role of only one hand is known. The question is this: To what extent do these actions show a consistent hand-use pattern that is identical to the one preferred by living people, in which the left hand acts in a supporting role, while the right hand performs fine manipulations?

The published data for hand-use patterns span the time range from the Acheulean to the present, including hominin species from *Australopithecus habilis* and *Homo ergaster* to Neanderthals and recent hunter-gatherers. These and the more recent data are described in greater detail by Steele and Uomini (2005 and 2009). This chapter presents the data and examines their biomechanical and experimental validity. The biomechanical constraints and assumptions behind the methodologies are scrutinized, and I report

the results from a series of actualistic experiments designed to test some of these assumptions. These knapping experiments were carried out at the Lejre Historical-Archaeological Research Center, Denmark, in 2005. The subjects were modern-day experimental knappers and archaeologists who agreed to participate in the study; the experiments were filmed on a Mini-DV camera and the data analyzed by replaying the films frame by frame (Uomini 2005).

### *Holding positions*

Archaeologists have written about evidence for handedness in artifacts for over 100 years (e.g., Wilson 1885; Cushing 1892; Brinton 1896; Rust 1973–1974; Montagu 1976). Many of these instances were subjective judgments that tools “fit” better in the right hand, based on intuitive suppositions of how the tools were held. For example, de Mortillet (1883) found that most “hand-stones” of “very early tribes” found in the Somme gravels were “made” for right-handed use. Similar declarations were also made by Black et al. (1933) about the Zhoukoudian artifacts in China (dated to 800,000–600,000 years). More recent authors such as Takeoka (1991), Phillipson (1997), and Posnansky (1959) do take grip position into account, showing that it is possible to include such observations in serious research. For example, Phillipson (1997, 174) observes that an asymmetrical weight distribution on a biface can facilitate use:

A hand-hold was provided by a retained area of the original cortex or a flake striking platform on an otherwise bifacially worked specimen. In most instances this more rounded area was associated with an asymmetric bulge on one or both faces of the handaxe which fit comfortably into the concavity of the user’s grasp and greatly facilitated the controlled manipulation of the tool.

Drawing on these experiments, Phillipson scrutinized 54 handaxes and cleavers recovered by a 1931 Louis Leakey excavation in Kenya, with a stratigraphy dated to about 1 million years. Starting from the premise that the trailing face, not the leading face, of a used edge would show greater signs of use, Phillipson reconstructed possible grip types for each piece. Of 54 tools, 6 (11%) could be assigned to probable left-hand use, 45 (83%) to right-hand use, and 3 to an indeterminate use. The high proportion of right-handed bifaces in this assemblage suggests a minority of left-handers among

the population of tool users, without assuming that one tool belonged to one person. The sum of all use-wear traces is simply taken to represent the sum of tool usage by all people; therefore, the findings suggest that the majority of users were right handed.

A similar observation on the use-constraining effects of asymmetrical weight distribution in artifacts was made by Posnansky (1959) for a collection of Early to Middle Acheulean handaxes from the Trent Valley (UK) and 118 handaxes from the Furze Platt site (UK). Posnansky (1959, 42) states that “it is found that the displacement of the weight away from the cutting edge, which a non-central median ridge implies, increases the efficiency for cutting.” Like Phillipson, Posnansky tested the handaxes for ease of use in either hand, assuming a cutting function where the handaxe butt is held in the palm of the hand. These early assemblages may be worth revisiting now that the methods of gripping and using tools are becoming better known, thanks to techniques such as scanning electron microscopy (Longo & Skakun 2008). Semenov’s volume (1957/1964) is a good example of the level of detail that can be obtained in a use-wear study to specify the precise kinds of hand configuration that were used to grip tools during their use. If the efficiency of the use of a handaxe is constrained by the holding position, then the slight asymmetries sometimes present in its form may suffice to determine a preference for the right or left hand.

### **Single-platform core rotation**

The influential study by Toth (1985b), which is considered a seminal study in the archaeology of prehistoric handedness, is based on the preferential direction of core rotation during single-platform flaking. In other words, the hand holding the core was responsible for the flaking sequence. The direction of rotation of the core was inferred from the presence of cortex on the right or left side of the dorsal surface of a flake. These single-platform cores were produced by removing all the flakes from the same platform. On a round cobble, this reduces the number of possible flaking locations to two: to the left of the previous removal, or to the right of it. A right-biased flake has cortex on the right, and vice versa. Toth’s methodology for interpreting handedness counts the proportions of left-cortex to right-cortex flakes within an assemblage. Each individual flake shows only whether it was removed to the left or right of the previous flake; it is the analysis of multiple flakes that yields data.

Applying the methodology to archaeological flakes, Toth (1985b) reports a 57:43 ratio of right to left flakes in assemblages from Koobi Fora, Kenya. Unfortunately, this publication has experienced what Boë & Iranzo (1994) term the “erroneous diffusion of scientific ideas.” One of the most problematic features is that authors interpret Toth’s findings, that is, a ratio of 57:43 right-oriented “flakes,” as meaning there was a ratio of 57:43 right-handed “hominins.” This type of error is well known and often emerges through the citing of articles from secondary sources (Sarringhaus et al. 2005).

However, it is unclear whether all of the flakes studied from this conglomeration of sites derived from single-platform reduction methods. The Karari scrapers or core scrapers that were flaked this way were uncovered at site FxJj 18GL and dated to around 1.5 million years (Toth 1982; note that each site at Koobi Fora has a tag consisting of a four-letter coordinate identifier and the number of the site). The Karari industry is defined as “a range of Oldowan forms, especially core scrapers and flake scrapers,” and these were produced with Reduction Mode 20, which is the single-platform flaking sequence (Toth 1982). Additional flakes from other sites were also used in the later Toth (1985b) publication: the sites of FxJj 1, FxJj 3, FxJj 10, and FxJj 50, which consist of KBS industry material; FxJj 33, a Megacore site; and FxJj 63, which contains unifacial picks attributed to the Early Acheulean industrial complex and is dated to approximately 1.3 to 0.7 million years. In the earlier publication, Toth (1982) describes the KBS industry as “a range of Oldowan forms, with few or no core and flake scrapers.” Therefore, it is possible that some of the flakes used in the later Toth (1985b) report were not single-platform flakes. Furthermore, the 1985 article did not report the percentage of flakes that could be assessed by using the methodology; this figure is about 20% for both experimental and archaeological flakes (Toth 1982). The data from these earlier publications show that Toth’s experimental production of core scrapers using Reduction Mode 20 yielded 266 flakes, of which 36 were left-cortical (13%) and 33 were right-cortical (12%) flakes. The archaeological site FxJj 18GL, which is the only site to contain Karari industry material, yielded 514 flakes, of which 46 are left-cortical (9%) and 62 are right-cortical (12%) flakes. In conclusion, a closer look at the data suggests that the published result of 57:43 should be interpreted with caution.

Notwithstanding the interpretation of the archaeological data, it is worth checking whether the methodology itself is valid. Toth (1985b) justifies the methodology by claiming that a right-handed knapper produces a high

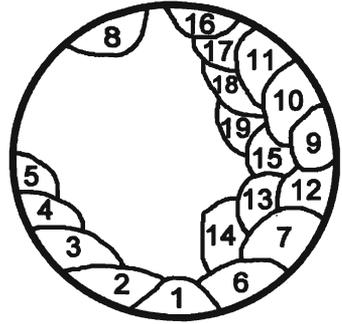
proportion of right-biased flakes. According to this author, during his own experimental core scraper replications, he consistently rotates the core clockwise in his left hand, thus knapping each flake to the right of the previous one. This resulted in a ratio of 56:44 right-biased flakes. He argued that this decision may be dictated by “the musculo-skeletal structure of the left hand and arm, in which the superior power of the supinators and flexors produce a preferential rotation in this direction for a stronger and more controlled turning motion (O. Lovejoy, pers.com.)” (Toth 1985b, 611). However, even if such a biomechanical preference did exist, it would be irrelevant for single-platform flaking unless it could be proven that there is a need for a strong or controlled turning motion in the core hand. The core scraper video knapping experiments, subsequently described, queried this assumption. In fact, the core (left) hand tends to hold the core in place to receive the hammerstone blow and the turning only occurs *in between* blows, where it does not affect the quality of the flakes.

### **Experimental test of the core-rotation paradigm**

Single-platform reduction sequences were filmed for five right-handed knappers and one left-handed knapper. Subjects were asked to strike flakes from a single platform with no other intention. By giving the subjects a simple instruction to flake from a single platform without attending to the shape of the core, it was hoped this task would reveal whether knappers have a natural tendency to remove each flake to the right of the previous one, as predicted by Toth (1985b). Results show that none of the six subjects in the core-rotation experiment flaked their single-platform cores with a unidirectional clockwise rotation. Rather, they usually alternated sequences of clockwise and anticlockwise rotation (Figure 5.1). The next removal tended to be dictated by the shape of the core and the relative prominence of ridges rather than by any biomechanical constraints on wrist motion. The four subjects (three right-handed and one left-handed) who did show some sequences of serial flaking actually favored a direction that was the opposite of what Toth predicted. If there were a biomechanical explanation for this, it would indicate that an outward rotation direction (wrist extension and supination) was favored by these experimental knappers.

Other large-scale studies also found that the order of flake detachment was mostly contingent on the shape of the core or flint nodule (Patterson & Sollberger 1986; Pobiner 1999). However, an experiment by Ludwig and

FIGURE 5.1. Single-platform core-reduction sequence for a participant's second core. (Drawings by N. Uomini.)



Harris (1994) confirmed that right-handers rotated the core clockwise and left-handers counterclockwise when making Karari scrapers. These conflicting results indicate caution in applying Toth's methodology to industries whose reduction strategies were not restricted to single-platform serial flaking. With other flaking strategies, the figures seem to approach 50:50 as the sample sizes increase (Noble & Davidson 1996, 170; Pobiner 1999; Uomini 2001). It may be true that Toth has an idiosyncratic preference to flake single-platform cores in a strictly unidirectional, rightward order, but this cannot be attributed to any biomechanical constraints, nor can the assumption be extended to other lithic industries. In conclusion, the assumptions underlying the interpretation of handedness at the Lower Palaeolithic site of Koobi Fora are not yet validated, which means that Toth's (1985b) claim to the oldest evidence for handedness is not supported.

### *Twisted ovates*

Reduction strategies can interact with the manner of holding the core in direct percussion. White (1998a) experimentally identified four possible bimanual configurations for manufacturing twisted ovates, two for each handedness pattern. These bifaces exist in British sites dated to between Late Oxygen Isotope Stage (OIS) 11 and Early OIS 10 (362,000 and 334,000 years), and, in France, they are found at sites with dates from OIS 12 to OIS 8 (478,000 to 242,000 years).

According to experiments done by White (1998a), twisted ovates can be produced with a particular method, usually at the finishing stage: First, one quarter of the edge is flaked unifacially. Then, the handaxe is inverted about the long axis and one quarter of the opposite face is flaked. These two sets

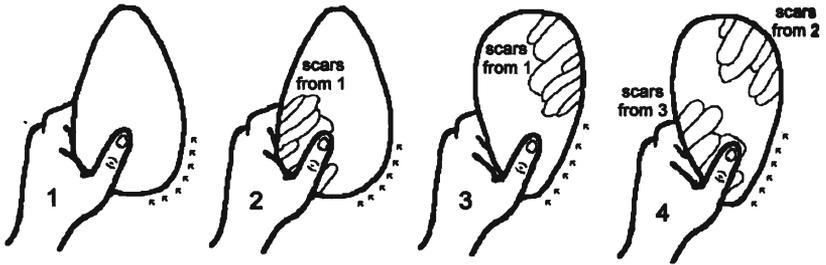
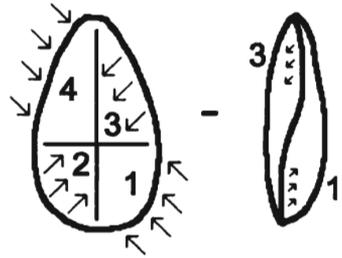


FIGURE 5.2. Diagram of a proposed knapping sequence for Z-shaped twisted ovates. (Drawings by N. Uomini.)

of unifacial removals, on opposing faces, are now joined at one tip of the handaxe. Next, the piece is rotated (clockwise or counterclockwise)  $180^\circ$  and one more quarter flaked unifacially. Finally, the piece is inverted about the long axis again and the opposite quarter is flaked, bringing the last two sets of removals to join at the other end of the handaxe. The result is a handaxe with an edge alternating four times between the two faces (Figure 5.2). This makes the profile look “twisted” in the same way, no matter how it is held (Figure 5.3).

In this reduction method, for all four edges that are knapped unifacially, it is the handaxe that is rotated so that the hammer hand always knaps in the same “active zone” of the core hand (White 1998a, 99). The interpretation of handedness comes from the fact that nearly all archaeological twisted ovates have a Z-shaped profile rather than an S-shaped profile. This means that the Z-twist knappers had two possibilities for the knapping zone (or quarter of the handaxe face): either the area near the wrist for a right-hander, or the area near the fingers for a left-hander. (A right-hander using the fingers area, as well as a left-hander using the wrist area, would produce an S-twist.) If it is the case that one biface represents one knapper, then the proportions of right-handed twisted ovates should reflect population handedness. The use of the fingers quarter can only be justified if the prehistoric knappers were mostly left handed, and so this possibility can be excluded, leaving only the right-handed option if the reduction strategy is correct. In summary, the high proportion of Z-twisted ovates in the British and French records is compatible with a preponderance of right-handed knappers between 478,000 and 242,000 years, which corresponds to *Homo heidelbergensis*.

FIGURE 5.3. Diagram of a Z-shaped twisted ovate profile. (Drawings by N. Uomini.)



### Drilling

Keeley (1977) describes a biface from Clacton, UK (Lower Palaeolithic) with microscopic use-wear showing it was used with a vertical rotating motion, such as boring holes, in a clockwise direction. Microwear polish and edge damage indicate the principal direction of turning (Cahen et al. 1979, 681). Keeley's argument implies that greater torque forces are exerted during wrist supination (clockwise for a right-hander) than pronation. The mode of prehension is not specified, but a tool being vertically rotated can be held either with the elbow up and palm facing outward (screwdriver grip), or with the elbow down and palm inward (stabbing grip). This presupposes that whatever the grip on the tool, people drill in a direction outward from the center. In a screwdriver grip, the wrist must produce mainly supinating forces; whereas drilling with a stabbing grip, the wrist produces mainly extensor forces. Both of these could reflect a preference to supination and extension rather than pronation and flexion (which would be the forces required if the drilling motion went inward). Cahen et al. (1979, 668) confirm this constraint.

Although a back-and-forth turning of the borer is efficient when the borer is hand-held, the outward turn of the wrist is more powerful. Experimental observations have shown that the return stroke in the weaker, inward direction is usually accompanied by a slackening of the vertical pressure.

In other words, boring is usually done with a back-and-forth motion, but the outward stroke produces the bulk of the striations. Therefore, the finding of clockwise drilling by Keeley (1977) is consistent with a right-handed user for this artifact.

*Skewed cone of percussion*

An experimental study of flake production was done by Rugg and Mullane (2001) on the skew of the Hertzian cone of percussion. These authors made the following hypothesis (Rugg & Mullane 2001, 252):

The angle at which the cone of percussion occurs relative to the striking platform is usually around 90 degrees, but can vary. . . . Because the human arm has pivot points at the shoulder, elbow and wrist, it is plausible that some blows would lead to cones of percussion that were angled to the right or left relative to the striking platform.

Because the Hertzian cone indicates directionality, its skew should reflect the exact trajectory of the hammerstone. With respect to knapping gestures, Takeoka (1991) defines two kinds of movement that affect the position of the flake blank (or core) and thus the angle at which it receives the hammerstone blows. One is wrist abduction or adduction; the other is forearm pronation or supination. When one is knapping, the axis of wrist movement (if the palm is placed flat on a table, this would be a side-to-side motion of the hand) affects the direction of fracture force propagation within the core; this is the effect that the cone of percussion hypothesis (subsequently described) exploits, although Rugg and Mullane (2001) argue for an entirely hammerstone-based cause. Forearm rotation affects the working angle (angle between the platform and hammerstone trajectory); a more pronated wrist results in an obtuse angle (because the platform is tilted toward the body), whereas a more supinated wrist results in an acute angle (platform tilted away from the body). A third factor, wrist flexion or extension, affects the horizontal position of the striking platform, bringing it closer to the knapper's eyes (Takeoka 1991, 503–505).

Rugg & Mullane (2001) experimentally validated their recognition criteria, with four left-handed knappers and four right-handed knappers: In a blind test, three people were able to assign 75% of the flakes to the correct handedness. The fact that right-handers produced right-skewed cones and left-handers produced left-skewed ones indicates that the tendency to skew the blow comes from either slight, unintended supination of the wrist or unintended flexion at the elbow of the knapping arm. If we assume that the basic knapping gesture for hard-hammer direct percussion consists of partially pronating the wrist and simultaneously adducting the forearm,

then any deviation to orient the blow toward one's body is caused by extra supination, flexion, or both.

Although this study is based on such biomechanical assumptions, these remain to be fully validated and applied systematically to archaeological collections. When this methodology was applied to Lower Palaeolithic flakes from Swanscombe and Purfleet (UK), equal proportions of left-skewed and right-skewed flakes were found. Furthermore, only a small subset of the flakes was measurable, and the measuring method was very difficult to implement objectively (Uomini 2001).

### *Lateralized resharpening and tranchet flakes*

Cornford (1986) describes evidence of handedness from asymmetrically retouched tools. This asymmetry can result from lateralized use, making it necessary to retouch the more worn side of the tool, or simply from constraints in knapping when one is holding the piece. This latter assumption is the basis of Cornford's (1986) argument about flakes resulting from a *coup du tranchet*. The site of La Cotte de St. Brelade (Jersey) has a long stratigraphy spanning the last two interglacials (from 240,000 to 122,000 years). These scrapers possess a burin plan, which is called a longitudinally struck flake (LSF), along the working edge that "creates a new edge of the greatest possible length and sharpness on the parent tool" (Cornford 1986, 337). Cornford argues that the hand used is constrained by the holding position for knapping because the knappers preferred to remove LSFs from the same edge as the gripped edge.

The interpretation of the knapper's handedness is based on an underlying assumption about biomechanical constraints on holding positions when one is knapping the long and transverse sharpening flakes. Cornford (1986) noted that most of the LSFs at the site were removed from the same corner of the tool, regardless of the tool's orientation. Cornford's replication experiment showed that a right-handed knapper was unable to make LSFs when striking on the opposite edge, meaning that the removal location chosen by the La Cotte knappers was the preferred one for a right-handed knapper. Of 1,302 unbroken LSFs, 79% were removed from the right distal end of the dorsal or ventral surface and from the left proximal end of the dorsal surface. However, by far the most frequent removal location was the distal right end of the dorsal surface, accounting for just over 50% of the

assemblage. All of these removal locations are achieved with the same holding position. The proportion of 79% is taken as representing a right-handed preference among the population of Neanderthal knappers at the site.

Cornford (1986) proposes a slightly different argument for transverse sharpening flakes (TSFs). The biomechanical constraints for TSFs are different from those for LSFs. These flakes can be struck with a blow that is either perpendicular to the edge of the tool or oblique to it. A perpendicular blow results in a TSF that shows its point of percussion located at the center of the butt. An oblique blow results in a point of percussion located at one end of the TSF's butt. This shift can be achieved by changing the relative positions of the tool edge and the striking arm. Combined with the holding constraint that the struck edge must be opposite to the gripped edge, this leads to Cornford's interpretation that a point of percussion located at the right end of the butt represents a right-hander's knapping, and vice versa. Of 288 TSFs, about 53% were struck with an oblique right-handed angle, 32% with a perpendicular angle, and 15% with an oblique left-handed angle.

#### *Tranchet flake production constraints*

A new methodology derived from Cornford's methodology was applied to tranchet flakes and handaxes from Boxgrove, UK. This Middle Pleistocene site was described in the first volume of the published monograph by Roberts and Parfitt (1999) and summarized in Roberts et al. (1997). The site is unique in that it has preserved many in situ remains, both lithic and faunal. The archaeological horizon was formed in a time span of about 100 years between OIS 13 (525,000 years) and OIS 12 (428,000 years). This site yielded hominin remains, a partial tibia of *Homo heidelbergensis*, and two lower incisors from one *Homo heidelbergensis* individual. Butchered horse remains were found near a former water hole (Pope & Roberts 2005), surrounded by eight in situ scatters of biface or biface roughout production containing all stages of debitage except for the bifaces themselves; several species of large mammals were also butchered here. The site is interpreted as a place of repeated use, where handaxes were knapped and used and then removed, whereas the debitage was left in place (Pope 2004).

For the analysis of laterality in this material, a simple count of right- and left-sided tranchet flakes and negatives led to a computation of their ratio in the assemblage. This is reported in detail in Uomini (2006). In addition, a knapping experiment was conducted to replicate the Boxgrove tranchet

handaxes and to test the holding constraints that Cornford had proposed for her material.

Seven right-handed knappers were asked to produce tranchet flakes on handaxes that they had made. Four subjects produced one of each right-struck and left-struck tranchet removal; only three knappers always used the same direction. Therefore, the Cornford (1986) hypothesis of holding restrictions did not apply to these knappers; their hand preference does not constrain the laterality of their tranchet removals. Although this study tested a small number of subjects, it has revealed the important fact that, once they are proficient enough to knap a tranchet flake, knappers can produce many different kinds of intended flakes. Therefore, there is no biomechanical constraint inducing the production of lateralized tranchet flakes. Given this absence of physical constraints on tranchet flaking, any evidence of cultural constraints, if they exist, would be expected to appear in the archaeological assemblage.

The 314 Boxgrove handaxes that were found to have one or more tranchet scars on the tip yielded 446 tranchet negatives. There is a statistically significantly higher proportion of left-struck tranchet scars (245 = 55% of 446). The ratio of left to right scars is statistically different from chance (binomial test, two-tailed  $p = .042$ ;  $\chi^2(1, N = 446) = 4.341, p = .037$ ), shown by the fact that  $p < .05$  in both cases (Clegg 1982, 175).

Among the 66 Boxgrove flakes that were counted as tranchet flakes, the numbers of right- and left-struck flakes are not statistically different from chance according to the binomial test (two-tailed  $p = .109$ ) and the chi-squared test:  $\chi^2(1, N = 66) = 2.970, p = .085$ . Adding to these figures, the previous data from Quarries 2C and 2D, analyzed by Wenban-Smith (personal communication, 2005), the total proportions are not statistically different from chance: two-tailed binomial  $p = .338$ ;  $\chi^2(1, N = 109) = 1.110, p = .292$ . However, the tendency to more left-struck flakes is consistent with the significantly higher proportion of left-struck than right-struck negatives on the handaxes.

These results show that the Boxgrove knappers preferred to strike tranchet flakes from the left, and thus were possibly discriminating between leftward and rightward striking directions. However, this could also be a result of well-established motor habits. It is possible that the prehistoric knappers tended to consistently make the same laterally struck tranchets out of habit, just as we do today with many manual activities. The difference between archaeological and experimental proportions could indicate a different

knapping style. In fact, the experiments suggested that the direction of a tranchet blow depends partly on whether the biface is held freehand or supported against the leg. Specifically, the experimental right-handed knappers tended to favor making a right-struck tranchet when the handaxe was held freehand, whereas the left-struck tranchets were facilitated by supporting the handaxe on either leg. The act of knapping freehand might be more strongly subject to handedness constraints because there are more degrees of freedom to control (cf. Steele, Quinlan, & Wenban-Smith 1995). In contrast, the reduction of degrees of freedom achieved by supporting the core on the leg might reduce the difficulty of the task, thus placing less pressure on the bimanual system to conform to a pattern of handedness. In this way, right-handers can produce the more “difficult” left-struck tranchet flakes.

Another explanation for the discrepancy between the archaeological and experimental tranchet results might be differences in tranchet-production techniques and methods. On the level of techniques, some show similarities (such as the use of an antler hammer), but other aspects of technique are not known for Boxgrove (knapping postures and bimanual configurations). The experiments were expected to allow reconstruction of the Lower Palaeolithic configurations for knapping tranchet flakes based on holding constraints. Although they did not evidence constraints, they did show that a huge range of variation can exist in holding positions, even among fewer than 10 knappers. These holding positions are idiosyncratic and do not affect the lateralization of the knapped product.

On the level of the method, the experiments make it clear that the tranchet method for British Lower Palaeolithic bifaces is not analogous to the LSF and TSF methods at La Cotte (e.g., Cornford 1986, 348). In technological terms, bifaces are generally symmetrical, meaning that both edges have roughly the same thinness and thus have equal potential to withstand a tranchet removal. In contrast, scrapers made on flakes could carry constraints on the removal location of sharpening flakes (J. McNabb, personal communication, 2005): the proximal end of the flake is thickest because of the bulb, and the distal end, being thinnest, cannot always sustain being gripped firmly in the hand. In conclusion, the resharpening method of *coup du tranchet* on Boxgrove handaxes did not have the same constraints as for the La Cotte material. Therefore, the Boxgrove bifaces do not yield any information on the handedness of their knappers.

*Summary of archaeological evidence*

The biomechanical assumptions underlying most of the methodologies may be sound, but many lack either robust data or experimental validation. The analysis of biface holding positions and edge damage by Phillipson (1997) could be improved with scanning electron microscopic analyses, for instance. The twisted ovate methodology, cone of percussion skew, and drilling marks remain to be systematically applied to archaeological assemblages. The most robust data exist for the Neanderthals who resharpened their scrapers at La Cotte de St. Brelade; incidentally, the fossil skeletal evidence for laterality also shows strong right-handedness among Neanderthals (Steele & Uomini 2005; Cashmore et al. 2008; Uomini in press).

With respect to two of the hypothesized markers of handedness already discussed, the actualistic experiments revealed that none of the underlying assumptions could be confirmed: Single-platform cores were not flaked unidirectionally based on a clockwise wrist rotation (core-rotation experiment); and tranchet flakes can be produced either in a right-struck or left-struck manner by knappers who are proficient enough to produce a tranchet flake in the first place (tranchet experiment). The consistent pattern seen at Boxgrove could be evidence of the well-established motor habits of knappers. The extremely difficult action of knapping tranchet flakes was evidently mastered by the palaeohominins in Britain. According to the bimanual model outlined herein, a more stable hand-use pattern is predicted by a more difficult task. This predicted that tranchet flakes should be strongly subjected to consistent motor patterns, and, in turn, that these would appear in the lateralized features of handaxe manufacture. This is endorsed to some extent by the leftward preference at Boxgrove.

These findings call for more research into the biomechanically constrained aspects of stone knapping, where left- and right-handed configurations should show opposite features. However, it is difficult to identify which features are good candidates. Unfortunately, the use of tools in prehistory is strongly tied to skill, simply because of the nature of the tools that require a learning period to master. Related to this is the direct usefulness of language in the learning of technological actions such as stone knapping. The final section of this chapter explores the question of whether language is necessary to learn such skills, or if it can be considered a by-product of mastering technology.

## Language and knapping

Experimental and ethnographic evidence from modern-day humans, as well as comparative ethological data from nonhuman apes, can provide some clues to the necessary and sufficient conditions for the transmission of knapping skills. Actualistic experiments designed to test the role of language in the learning of specific knapping methods are few. One study showed that verbal communication was not necessary to transmit the basics of quarrying raw material and beginning to reduce it (Petraglia et al. 2005, 216). Another study concluded that nonverbal communication was sufficient to transmit the concept of the Levallois method, judging by all stages of core preparation and successful detachment of a Levallois flake (Ohnuma et al. 1997). However, both studies failed to exclude language, instead limiting speech. The quarrying experiment permitted “demonstrative gestures,” whereas the subjects of the Levallois experiment were allowed to ask questions and receive answers “by gesture alone.” This suggests that participants were not prevented from using a linguistic mode of cognition; rather, they were simply prevented from using speech. These studies therefore make interesting conclusions about the role of speech in knapping, but they do not provide any information about language itself.

Reports of ethnographic parallels for apprenticeship are especially relevant here, notably in documenting the variety of learning strategies that living humans employ today. Particularly, they can show which elements of teaching are verbalized when they do become explicitly taught. They also show how much learning can occur without verbalized instruction (Burling 1986). For instance, with reference to toolmaking, Pearce (2005, 236) points out that storytelling is common when people are not talking about the toolmaking process:

In at least a number of hunter-gatherer societies, knowledge is transmitted indirectly through narrative descriptions of events. This occurs in the Yup'ik of the Western Alaskan coast, . . . it occurs in the Northern Dene of the Canadian Subarctic, . . . and it occurs in the !Kung. . . . The !Kung, for example, spend much of their time conversing – not instructing – while they make tools and gifts. . . . They make their tools slowly and talk quickly.

Furthermore, many oral-tradition societies have rich technical vocabularies related to crafts that are not used in apprenticeship but rather “to comment, on occasion, on what is being taught by imitation” (de Beaune

2002, 716). Still, it is likely that this vocabulary gives learners the chance to reflect consciously on their craft, thus making it explicitly linguistic.

These scenarios point to an active role of language during tool manufacture, even if language is not directly applied to the process itself. This indicates that linguistic cognition is present in the toolmaker's mind. In turn, the option of using this cognition to reflect on the toolmaking process cannot be excluded. Learners who could use their language skills to reflect consciously and conceptually on their own actions and their perception of others' actions may have been able to acquire the difficult skills of stone knapping more efficiently.

## Conclusion

The Complementary Role Differentiation model of handedness, derived from Guiard's (1987) framework, was put to the test of archaeological evidence for hand roles. This revealed an ancient and consistent tendency toward right-handedness, although the data are scant. The hominin species that are related to the most reliable data are the Neanderthals. The earlier data from Acheulean industries were not confirmed through actualistic knapping experiments. However, the lack of validation of these potential markers of handedness cannot be taken as evidence against language capacities in these hominins. Many authors agree that language emerged before the Lower Palaeolithic period. For example, Belfer-Cohen and Goren-Inbar (1994) and Dor and Jablonka (2004) argue for language abilities in *Homo erectus*, and Aiello (1998) similarly places language origins within the realm of *Homo ergaster*. Others such as Wynn (1991a) and Graves (1994) reject the idea that archaeology can inform language origins, although Wynn assigns certain cognitive abilities to the knappers of Acheulean handaxes that may relate to linguistic abilities. The well-established right-biased hand-use pattern of Lower and Middle Palaeolithic hominins implies that asymmetries in manual function were already present in the Pliocene epoch. If the link between handedness and language does exist, as many authors accept (Zangwill 1960; Hécaen & de Ajuriaguerra 1964; Bradshaw & Rogers 1993; Corballis 1998), then this would make the origins of language much more ancient than previously thought. It is hoped that this chapter has shown how neuropsychology can make a valuable contribution to archaeology, in studying the emergence of cognitive abilities related to language and handedness.

## CHAPTER 6

### How to think a simple spear

*Miriam Noël Haidle*

Prehistoric behavior and, even more so, knowledge and cognition are not easily accessible. The most important means of approaching these nonphysical aspects of human life can be found in the material remains of the past behavior: artifacts. Yet, not all behavior, and even less thought, left physical traces, and not all the traces that once existed have survived over time. Thus, only a fraction of a prehistoric population's corpus of behavior, knowledge, and cognition – and rarely that of individuals – can, theoretically, be detected by their remains in the archaeological record (Haidle 2007). Yet, whose behavior, knowledge, and cognition are we looking at? Our own anatomical species, *Homo sapiens*, can be traced back some 200,000 years to its origins in East Africa. About 100,000 years ago, *Homo sapiens* made its first attempt to expand to Southwest Asia, and took another 80,000 years to disperse over the whole Old World and reach the Americas. During most of the 2.5 million years of cultural history of mankind, species other than ours, species having cognitive capabilities other than ours, perceived needs, thought of solutions, and produced and used tools to satisfy those needs.

These two critical inconsistencies in the archaeological record – incomplete preservation of tools and variation in the cognitive faculties of species that produced those tools – pose special problems in examinations of the development of past behavior and the evolution of cognition. Although the loss of evidence cannot be rectified, one solution to the problem of assessing

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tool behavior across species is to identify a cognitive feature intrinsic to tools and tool behavior in general, yet independent of situational variables such as what needs were met by a tool, what tool material was used to solve the problem, or what other cognitive faculties the tool-using or tool-producing species possessed. Allowing the comparison of all kinds of animal tool behavior and hominin artifacts, this feature could open the broadest possible material database for the study of cognitive evolution. Furthermore, it would not discriminate against other species' behavior and cognitive capacity by evaluating them from a modern human perspective, but, instead, describe similarities and differences in an unbiased way.

A cognitive feature that could fulfill all the aforementioned requirements is increased problem–solution distance (Haidle 2006a, 2006b). Ground-breaking studies on differences in the problem-solving behavior of several animal species and humans were conducted by Wolfgang Köhler, an early experimental gestalt psychologist. On the basis of his studies, for which he examined mainly chimpanzees at a research camp of the Prussian Academy of Sciences on Tenerife in 1914–1917, Köhler created a model for the cognitive interpretation of tool use and production. In tool use, he recognized a progression from direct to “roundabout” thinking, that is, the achievement of goals by making a detour. The acting subject not only is able to focus on the solution to its need (e.g., a fruit to satisfy hunger), but can turn away from the immediate target to look for a tool that helps to solve an otherwise unsolvable problem (e.g., a stone to open a nut). In tool production, however, not only is a ready link (tool) looked for and used, but the roundabout way has to be extended to create an appropriate instrument to solve the perceived problem (Köhler 1925). This more or less extended problem–solution distance is a feature of every tool behavior, and it affords a means of examining tool behavior independently from the material, form, and function of the tool as well as the faculties of the acting species. Basic observations of differences in problem–solution distance in tool behavior have been made in animal experiments; for comparing recent animal behavior with prehistoric tools and developmental deductions from it, an efficient analytical instrument has to be designed.

### **The comparison of animal and hominin tool behavior**

Data sets on animal tool behavior and archaeological artifacts differ markedly. The majority of ethological studies do not primarily focus on tool behavior; observations of animal tool use are, therefore, often reported

as anecdotes in a setting that is not examined in detail for this purpose. Furthermore, the descriptions mostly concentrate on the behavior and its ecological, adaptive, social, motivational, or cognitive context, and less on the material and technological aspects of the tool. Archaeological artifact analyses, on the contrary, focus on material and technology and often leave the behavioral perspective aside. Thus, a direct comparison of animal and archaeological tools is impeded by differences in the primary data of the two scientific traditions (Wynn 1990).

Nonetheless, some approaches have been taken to merge these traditions, focusing on early hominin stone tool production and differentiating it from great apes' capabilities. For example, experiments with the orangutan Abang (Wright 1972) and the bonobo Kanzi (Toth et al. 1993; Schick et al. 1999) examined the great apes' ability to flake stone tools and to use them in a cutting problem. After analyzing morphotechnological differences between early hominin stone tools and accidental stone fragments at chimpanzee nut-cracking sites (Mercader et al. 2002), Mercader et al. (2007) were able to identify the first chimpanzee archaeological sites. Wynn and McGrew (1989) studied chimpanzee and Oldowan artifacts by using Jean Piaget's model of ontogenetic child development and found no differences in cognitive complexity regarding spatio-rational thought, except for the human extension of raw material transport. Still, behavioral and technological comparisons concluded that there are neither functional equivalents, nor similar motor patterns or corresponding motivations, regarding the use of stone tools in chimpanzees and in early hominins (Kortlandt 1986). All these approaches are focusing on early hominin stone tool production and its differentiation from great apes' faculties.

Another, more general method for evaluating cognitive complexity was developed for comparative technological analyses in anthropology and adapted for cognitive-archaeological studies. Through this method, the technological processes incorporated within a particular behavior are translated into operational sequences – *chaînes opératoires* – so that the basic conceptual schemes underlying a behavior can be approached. Beyries and Joulian (1990) describe the *chaînes opératoires* of 11 forms of tool use observed in seven animal species, noting, though, that there were problems in correlating the numbers of actions and action phases with the complexity of the *schéma conceptuel*.

In a second study, the *chaînes opératoires* in a chimpanzee's use of a hammer to open nuts is compared with the hominin production of an Oldowan chopper. Joulian (1996) concludes that the operational sequences

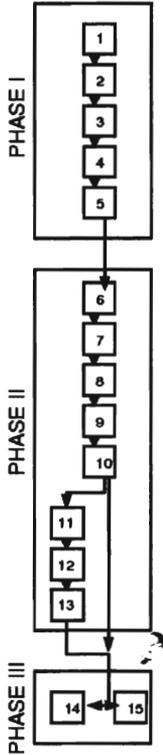
of these stone tool behaviors differ only slightly, with the nut-cracking behavior probably being a little more complex, requiring a higher number of action steps (Figure 6.1). The lesser complexity of the hominin example derives, however, from the different depth of observation and description of the action series that Joulian applies. Whereas his study of the nut-cracking process starts with the collection of the nuts and ends with their consumption, the knapping of an Oldowan tool is seen as a goal in itself, without regard to the role of the tool in a longer sequence as a means to satisfy a basic need such as the consumption of meat. Thus, the problem–solution distance for the production of the Oldowan tools is described only partially. In addition, only the single-action steps, not the different passive elements and active agents within these series of action steps, are clearly identified. Nevertheless, if these problems can be overcome, *chaînes opératoires* provide not only an important analytical method for describing technological processes, but also a promising starting point for the study of cognitive complexity.

### Cognigrams

By combining the problem–solution distance approach with *chaînes opératoires* methodology, and by recording the data they produce in a cognigram, a means can be found for analyzing and coding tool behavior. The first step in coding tool behavior is to identify the foci of the individual in the specific action series (Figure 6.2a). Foci are all separate, discrete elements of attention that take part in the sequence: first the individual or subject itself respective to a certain physical or mental need, and then an object to be consumed or used to satisfy the need, probable tools, further objects, and locations. Active (A) agents and passive (P) elements must be differentiated; whereas an A-Focus is either acting like the subject itself or actively controlled by the subject, as in the case of a tool such as a stone hammer used to crack nuts, a P-Focus is a passive element not actively controlled, but acted on, such as a fruit to be eaten or a stone anvil on which nuts will be cracked.

The second step is to identify the probable perceptions of needs and problems that initiate the different foci and start the actions (Figure 6.2b). For example, an individual notices hunger as a current basic problem, thus opening the subject's A-Focus (the active subject itself). The individual then recognizes a subproblem in finding a good feeding object such as a

## Cracking of *Panda oleosa* Nuts



### PHASE I: Gathering nuts

1. Selection of tree / anvil
2. Search for hammerstone
3. Transport to anvil
4. Gathering nuts
5. Transport to anvil

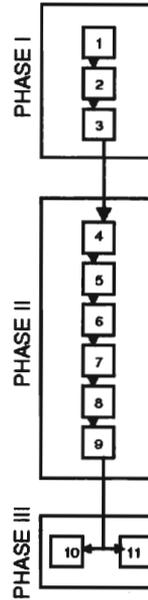
### PHASE II: Opening nuts

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



### PHASE I: Gathering raw material

1. Search for raw material
2. Search for hammerstone
3. Transport to atelier

### PHASE II: Knapping tool

4. Positioning of the individual
5. Positioning of raw material 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

FIGURE 6.1. *Chaînes opératoires* of the cracking of *Panda oleosa* nuts and the knapping of an Oldowan chopper as Joulain (1996) described them.

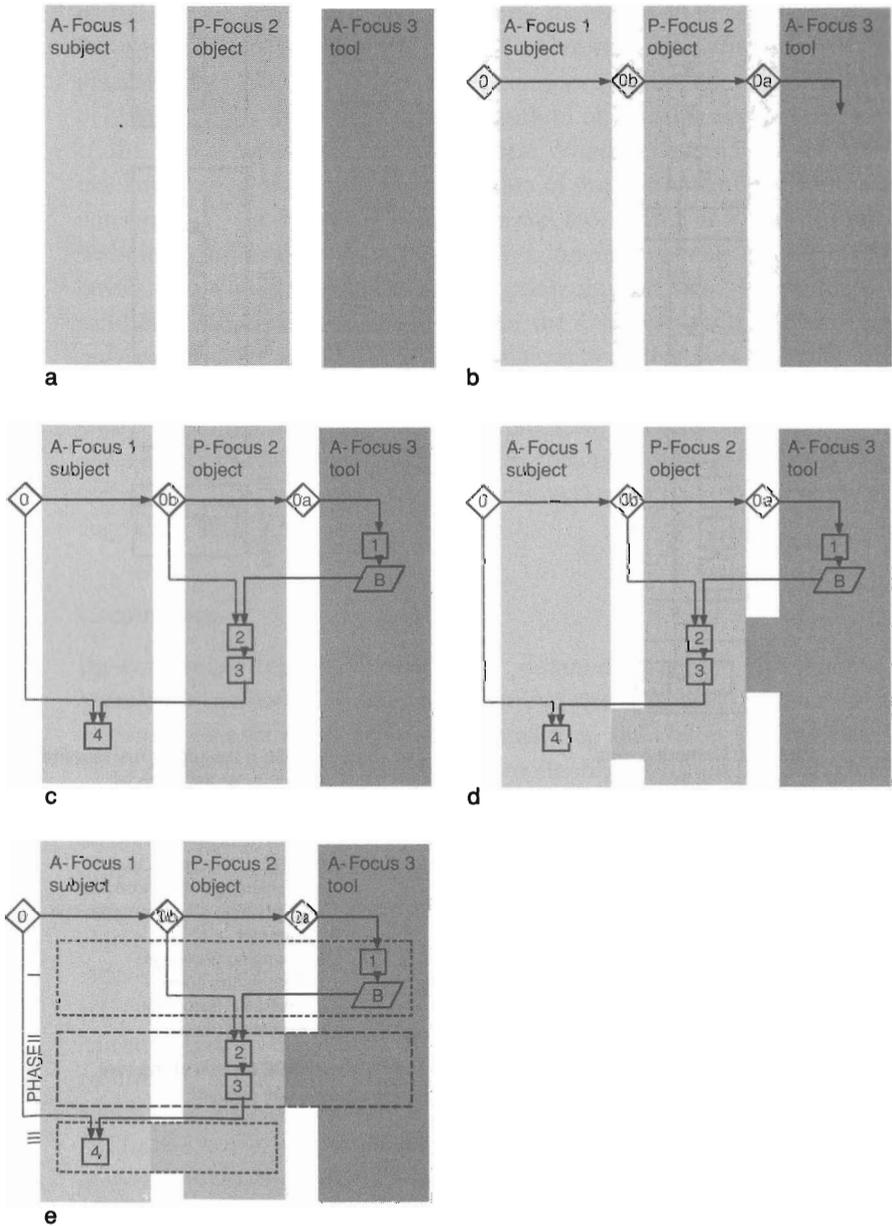


FIGURE 6.2. The different components of a cognigram: a, foci; b, perceptions; c, actions; d, effects; and e, phases.

fruit or a nut, thus opening another focus (P-Focus) on a passive object. Most of the fruits can be eaten at once, so no other focus of the individual has to be opened in this thought and action process; the action can be started to still the hunger and satisfy the basic need. The desire to feed on nuts, however, leads to the perception of a second subproblem, which is the need of a tool to crack the nut; thus a third focus is opened, which is the subject's A-Focus on a tool.

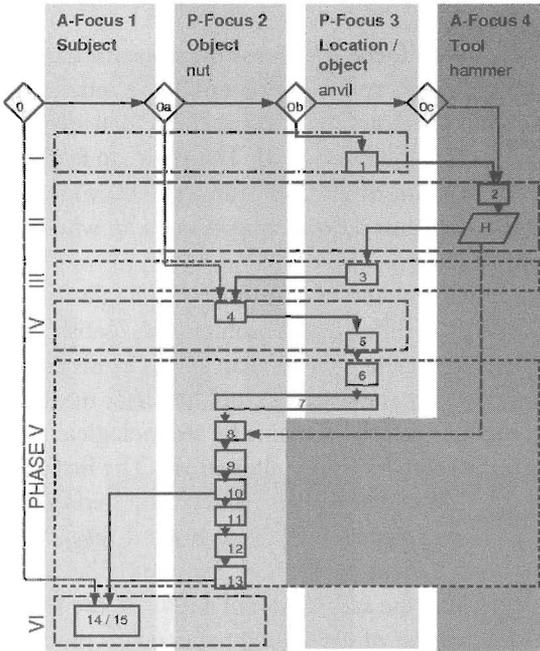
The third step is to identify the smallest action units, the single-action steps that must be taken to solve the different subproblems and satisfy the basic need (Figure 6.2c). Whereas all steps of action can ideally be observed in modern animal and human tool behavior, past tool behavior must be reconstructed from its incomplete material remains by technological and functional analysis, leaving some room for minor alternatives. The first step of action is initiated by the perception of a problem and is allocated to the corresponding focus. The following steps are assigned to their respective foci: the production of a tool in the focus on the tool, the manipulation of an object in the focus on the object, the satisfaction of a need in the focus on the subject, and so on. The course of the thought-and-action process, including possible feedback loops, is marked with arrows in Figure 6.2.

The fourth step is to identify actively controlled effects of an A-Focus – a focus on the subject or a tool – on another focus (Figure 6.2d). These are represented by bars spreading from the focus producing the effect to the foci receiving it. Effects are limited in time to the duration of the action steps in which an agent actually influences another focus, such as while a stone is hammering a nut.

The fifth and last step is to structure the thought-and-action processes by identifying the sequences of tightly linked actions that constitute their phases (Figure 6.2e). Examples of phases include the search for an object; the steps to produce a simple tool, such as a brush stick to probe for insects, by breaking off a branch, removing the bark, smaller twigs, and leaves, and chewing one end; or the final satisfaction of the basic need.

In comparing different tool behaviors, it is essential to consider the complete distance between each underlying problem and its final solution. Therefore, a thought-and-action process always starts with a basic need and ends in positive or negative satisfaction of this need. Coding the examples of Joulian's (1996) study in cognigrams reveals the differences between the opening of *Panda oleosa* nuts by chimpanzees and the knapping of an Oldowan chopper by hominins (Figures 6.3a and 6.3b), for analysis of

## Cracking of *Panda oleosa* nuts



a

- 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**

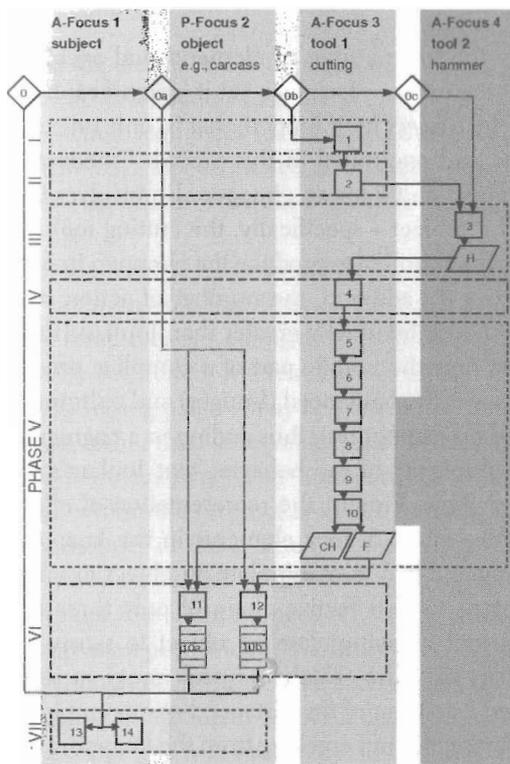
- 6. Positioning of individual
- 7. Positioning of nut on anvil
- 8. Taking hammer
- 9. Hammering (several times)
- 10. Putting hammer aside  
(if nut is open: Phase VI Satisfaction)
- 11. Repositioning nut
- 12. Hammering
- 13. Putting hammer aside

**Phase VI: Satisfaction of need**

- 14. Direct consumption
- 15. Indirect consumption

FIGURE 6.3. Detecting the differences with cognigrams of a, the cracking of *Panda oleosa* nuts and b, the knapping and use of an Oldowan chopper.

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



- b**
- 0. Perception of basic need: hunger
  - 0a. Perception subproblem 1: need of meat
  - 0b. Perception subproblem 2: need of cutting tool
  - 0c. Perception subproblem 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 workshop
- PHASE III: Search for tool 2**
- 3. Search for hammerstone
- PHASE IV: Transport of tool 2**
- 4. Transport of hammerstone to raw material / workshop
- PHASE V: Use of tool 2 / Production of tool 1**
- 5. Positioning of individual
  - 6. Positioning of raw material and hammerstone
  - 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**
- 13. Direct consumption
  - 14. Indirect consumption (e.g., sharing, feeding)

FIGURE 6.3 (cont.)

active and passive foci show the full number of elements and agents in the action process. Nut cracking involves four foci, yet it is significant that only one A-focus other than the subject itself is open; that is, only one tool, the hammer, is actively used and controlled in this process. In contrast, although the process of knapping an Oldowan chopper also involves four foci, two A-foci other than the subject – specifically, the cutting tool and the hammerstone – are actively controlled to produce the chopper; in sum, three of the four foci are active. In addition, the number of action steps in stone knapping is shown to be substantially greater than Joulian (1996) suggests because he describes only the middle part of a complete process that begins with the perception of the basic need (hunger) and culminates in the satisfaction of the need (consumption); thus coding in a cognigram yields information on the complexity of the behavior that Joulian's use of a *chaîne opératoire* cannot show. Finally, the representation of effects shows that there is an effective chain of four elements in the knapping of a chopper – a tool to produce a tool to manipulate an object to satisfy the subject's need – in contrast to an effective chain of only three foci in the cracking of nuts – a tool to manipulate an object to satisfy the subject's need. This secondary tool use (Kitahara-Frisch 1993) in stone knapping represents a marked extension of the distance between problem and solution and further differentiates nut cracking from the knapping of a chopper.

### A spear is a spear is a spear?

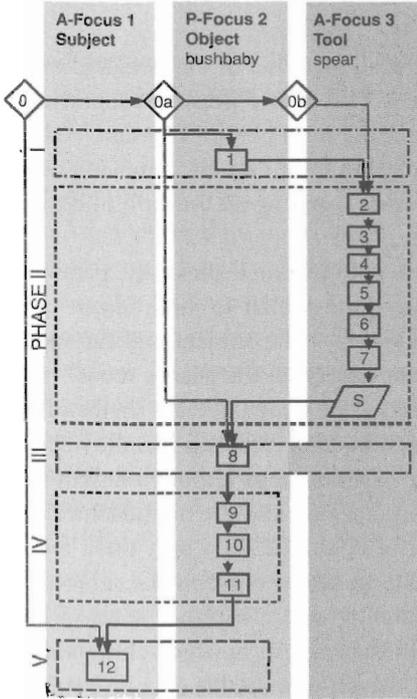
Regarding the complexity of the cognitive process, the production and use of spear-like tools seems not far beyond using a hammerstone to crack open nuts or knapping a chopper or flake to dissect a carcass. The employment of spear-like tools in hunting activities is evident for chimpanzees as well as for *Homo heidelbergensis*; a coding of both sequences of action in a cognigram can test for similarities or differences. At the Fongoli site in Senegal, several chimpanzees, including females, males, and immature animals of both sexes, were observed to use manufactured tools to hunt lesser bushbabies (*Galago senegalensis*), employing these tools not as probes or rousers but in the manner of spears or lances (Pruetz & Bertolani 2007). As nocturnal prey, the lesser bushbabies rest in hollow branches or tree trunks during the day, and the sticks, some of them with a trimmed tip, are jabbed in the hollow probably to immobilize the animals and prevent their escape

while the chimpanzees break off dead branches of the trees and otherwise improve their access to these prey. Pruetz and Bertolani report different production sequences for the tools; the most complex variant, coded here (Figure 6.4), is a sequence of breaking off a branch, removing twigs and leaves, trimming off one or both ends, stripping off the bark, and trimming the tip.

In the hunt of lesser bushbabies with trimmed sticks, the parameters of the problem–solution distance are quite similar to those of nut cracking: only three foci are open, two of which – the subject and the tool – are actively controlled, whereas the two aspects of the passive focus – the prey and its hiding place – may be seen as one entity, like the shell and pulp of a fruit, rather than as separate, unembedded elements like the nut and the anvil in nut cracking. The number of action steps, although slightly smaller, is still within the range of both nut cracking and the manufacture and use of a chopper or flake. The effective chain includes only three foci, as in nut cracking – a tool to manipulate an object to satisfy the subject's need. Although the circumstances of jabbing with a trimmed stick, of hunting mammalian prey, widens markedly the contexts in which chimpanzees use tools into those assumed to be exclusively human, the cognitive complexity regarding the problem–solution distance lies within the known range.

Accordingly, it is instructive to compare these chimpanzee tools with simple spears or lances from Lower and Middle Palaeolithic sites in Europe such as Schöningen, Lower Saxony, Germany (Thieme 1997, 1999); Clacton-on-Sea, England (Oakley et al. 1977; McNabb 1989); or Lehringen, Lower Saxony, Germany (Thieme & Veil 1985). At first glance, these human-made weapons do not appear much more complex than their animal counterparts. Of course, the tools are carefully worked with stone tools from selected yew and pine trees, and so a second glance recognizes an extended effective chain, or broadened object-planning behavior (Haidle 1999, 2000, 2004), in the use of a tool (e.g., hammerstone) to produce a tool (knapping a stone tool) to produce a tool (carve the wooden spear) to manipulate an object (hunt an animal) to satisfy the basic need (hunger). Reproduction experiments by Veil (1991) for the Lehringen lance assess the time merely to work the raw material at 4.5 to 5.5 hours, from cutting down the tree, removing the side branches, smoothing the bases of the branches, stripping off the bark, and reworking the form and surface of the spear to, finally, trimming the tip. Yet, as in Joulain's (1996) analysis of the process of knapping an Oldowan chopper, Veil's experimental setting covers only

# Hunting of *Galago senegalensis* by chimpanzees



- 0. Perception of basic need: hunger
- 0a. Perception subproblem 1: need of a bushbaby that hides in a dead branch
- 0b. Perception subproblem 3: need of a tool

**PHASE I: Selection of tree**

- 1. Locate potential nest cavity

**PHASE II: Production of tool**

- 2. Locate branch
- 3. Break off branch
- 4. Trim off leaves / side branches
- 5. Trim off one or both ends
- 6. Strip branch of bark
- 7. Sharpen tip of tool

**PHASE III: Use of tool**

- 8. Jab tool into hollow trunk / demobilize bushbaby

**PHASE IV: Getting access to prey**

- 9. Break off trunk with nest cavity
- 10. Enlarge cavity opening
- 11. Extract prey

**PHASE V: Satisfaction of need**

- 12. Direct consumption of bushbaby

FIGURE 6.4. Cognigram of the production and use of a wooden lance by chimpanzees to hunt *Galago senegalensis*.

part of the sequence of thoughts and actions for producing and using a wooden spear. Excluded are both the procurement of wood and stone as raw materials and the manufacture of the cutting and carving tools needed for production, so a direct comparison of the partial production process of the spear has to be embedded in a complete process from a basic problem to its final solution.

The cognigram for a Lower Palaeolithic spear given in Figure 6.5 can be no more than hypothetical, yet, it is based on realistic assumptions drawn from Veil's (1991) experiments, supported by the detailed analysis of the 300,000- to 400,000-year-old Schöningen spears (Thieme 1999) and supplemented with some commonsense assumptions about phases of raw-material procurement, transport of different elements, and the production of tools, as well as about repeated interruptions of the process by other urgent needs. Figure 6.5 includes the main foci and phases in a process that might take several days to reach the final goal; for the sake of clarity, the single-action steps are omitted. However, although the cognigram of the manufacture and use of a Lower Palaeolithic spear presented here is markedly simplified and abstracted, it nonetheless shows in every aspect – foci, perceptions, implicit action steps, phases, and effects – a far more complicated process than previously assumed. Its operational sequence comprises an effective chain of a minimum of five foci: the soft or hard hammerstones (1) to produce a handaxe and flake tool (2) to cut off the tree and carve the spear (3) to kill the animal (4) to satisfy the subject's need (5); if, for example, an antler percussion tool were included in the stone tool production, the effective chain would be accordingly lengthened (Figure 6.6).

### Decoupling of need and satisfaction

Compared to the chimpanzee and hominin examples given herein, activities that can be and generally are completed within minutes, the process of the Lower Palaeolithic spear is extremely extended in both duration and complexity. To think through and follow the operational sequence from the perception of the basic need (hunger for meat) to its final satisfaction would be very demanding and difficult. This and even higher modes of complexity in tool behavior are possible only by decoupling satisfaction and basic need, such that the manufacture and curation of tools becomes an aim and a satisfaction in and of itself, independent from actual basic

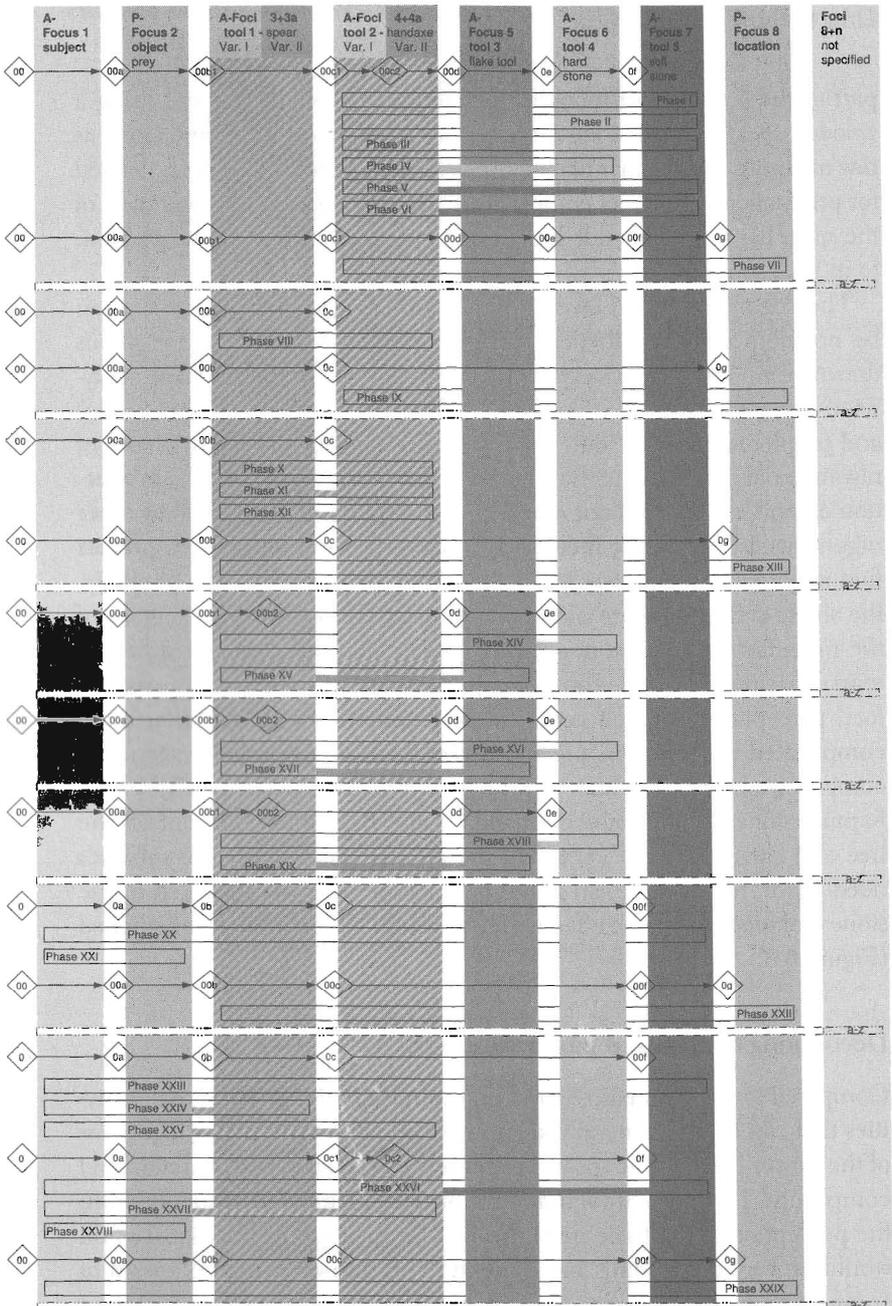


FIGURE 6.5. Cognigram of the production and use of a wooden spear by *Homo heidelbergensis* to hunt horses at Schöningen, Lower Saxony (the text includes all probable actions; the simplified chart is shown here, depicting only phases, not single actions).

**Production and use of a spear by *Homo heidelbergensis***

Perception	Phase	Description
00.		Basic need (in principle, semi-acute): hunger
00a.		Subproblem 1 (in principle, semi-acute): hunt prey
00b.		Subproblem 2 (in principle, semi-acute): need of spear (tool 1)
00c1.		Subproblem 3A (semi-acute): need of handaxe to cut down tree (tool 2): quality A
00c1.		Subproblem 3B (semi-acute): need of handaxe to cut down tree (tool 2): quality B
00d.		Subproblem 4 (semi-acute): need of flake tool (tool 3) to work wood
0e.		Subproblem 5 (acute): need of hard hammerstone (tool 4) to produce tool 3 and work on tool 2
0f.		Subproblem 6 (semi-acute): need of a soft hammerstone (tool 5) for retouch of tool 2
	I	Search for tool 5 (soft hammerstone)
	II	Transport tool 5 / Search for tool 4 (hard hammerstone)
	III	Transport tools 4, 5 / Search for raw material for tools 2 and 3
	IV	Production tool 2 / Use tool 4 → roughout of handaxe
	V	Production tool 2 / Use tool 5 → thinning
	VI	Production tool 2 / Use tool 5 → retouch
00-00f.		Basic need, subproblems 1-6 (in principle)
0g.		Subproblem 7 (acute): secure tools at site
	VII	Transport of tools 2, 4, 5 and raw material to site
	a-z	Several other activities (not related, not specified)
00-00b.		Basic need, subproblems 1-2 (in principle, semi-acute)
0c.		Subproblem 3 (acute)
	VIII	Search for raw material for tool 1 / transport tool 2
00-00b.		Basic need, subproblems 1-2 (in principle)
0c.		Subproblem 3 (acute)
0g.		Subproblem 7 (acute): secure tools at site
	IX	Transport tool 2 to site
	a-z	Several other activities (not related, not specified)
00-00b.		Basic need, subproblems 1-2 (in principle, semi-acute)
0c.		Subproblem 3 (acute)
	X	Search for raw material for tool 1 / transport tool 2
	XI	Production tool 1 / Use tool 2 → cut down tree
	XII	Production tool 1 / Use tool 2 → roughout of blank of spear
00-00b.		Basic need, subproblems 1-2 (in principle, semi-acute)
0c.		Subproblem 3 (acute)
0g.		subproblem 7 (acute): secure tools at site
	XIII	Transport blank 1 and tool 2 to site
	a-z	Several other activities (not related, not specified)
00-00a.		basic need, subproblem 1 (in principle, semi-acute)
00b1.		subproblem 2A (semi-acute): quality A
00b2.		subproblem 2B (semi-acute): quality B
0d-e.		subproblem 4-5 (acute)
	XIV	Production tool 3 / use tool 4
	XV	Production tool 1 / use tool 3 → rework bases of branches
	a-z	Several other activities (not related, not specified)
00-00a.		Basic need, subproblem 1 (in principle, semi-acute)
00b1.		Subproblem 2A (semi-acute): quality A
00b2.		Subproblem 2B (semi-acute): quality B
0d-e.		Subproblem 4-5 (acute)
	XVI	Production tool 3 / use tool 4
	XVII	Production tool 1 / use tool 3 → remove bark, rework form
	a-z	Several other activities (not related, not specified)
00-00a.		Basic need, subproblem 1 (in principle, semi-acute)
00b1.		Subproblem 2A (semi-acute): quality A
00b2.		Subproblem 2B (semi-acute): quality B
0d-e.		Subproblem 4-5 (acute)
	XVIII	Production tool 3 / use tool 4
	XIX	Production tool 1 / use tool 3 → rework form, carve tip
	a-z	Several other activities (not related, not specified)
0-0b.		Basic need, subproblems 1, 2 (semi-acute, acute)
0c.		Subproblem 3 (semi-acute): need of tool 2 (handaxe) to butcher prey
00f.		Subproblem 6 (semi-acute): need of tool 5 for retouch of tool 2
	XX	Search for prey / transport tools 1, 2, 5
	XXI	Satisfaction of need not successful → frustration
00-00a-c, f.		Basic need, subproblems 1, 2, 3 and 6 (semi-acute, in principle)
0g.		Subproblem 7 (acute): secure tools at site
	XXII	Transport tools 1, 2, and 5 to site
	a-z	Several other activities (not related, not specified)
0-0b.		Basic need, subproblems 1, 2 (semi-acute, acute)
0c.		Subproblem 3 (semi-acute): need of tool 2 (handaxe) to butcher prey
00f.		Subproblem 6 (semi-acute): need of tool 5 to resharpen tool 2
	XXIII	Search for prey / transport tools 1, 2, 5
	XXIV	Hunt / use tool 1 / transport tools 2, 5 → kill animal
	XXV	Butcher prey / use tool 2 A → remove skin
0-0a.		Basic need, subproblem 1 (acute)
0c1.		Subproblem 3A (acute): need of tool 2 (handaxe) to break open carcass: quality A
0c2.		Subproblem 3B (acute): need of tool 2 (handaxe) to break open carcass: quality B
0f.		Subproblem 6 (semi-acute): need of tool 5 (soft hammerstone) to sharpen tool 2
	XXVI	Retouch of tool 2 / use tool 5
	XXVII	Butcher prey / use tool 2 AB → break open and butcher carcass
	XXVIII	Satisfaction of need
00.		Basic need (semi-acute)
00a-c, f.		Subproblem 1-3 and 6 (semi-acute, in principle)
0g.		Subproblem 7 (acute): secure prey and tools 1, 2, 5 at site
	XXIX	Transport of parts of prey and tools 1, 2, 5 to site
	a-z	Several other activities (not related, not specified)

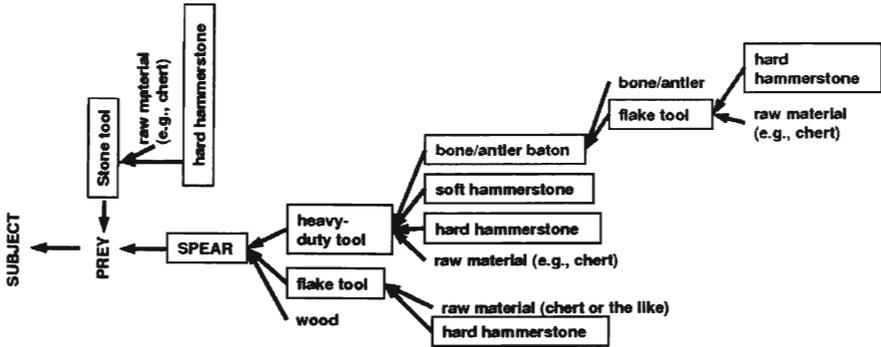


FIGURE 6.6. Effective chain of a simple spear from Schöningen, Lower Saxony.

needs. Thus, small operational units, each with its own intermediate aims, can be put together in a modular way into different operational sequences. An example demonstrating the effectiveness of making multiple use of a particular module within an operational sequence is shown in Figure 6.6: Hard hammerstones to knap stone artifacts need not be repeatedly looked for, used, and discarded, but, instead, kept so that they are instantly available for use when required. Thinking of tools not as means for a specific purpose, but as independent items with multiple potential purposes, opens the way to manufacturing and maintaining a general tool kit and to developing tools whose sufficiency extends beyond a specific, single task. Whereas a thought-and-action process in animal and early hominin tool behavior is generated by the perception of a problem for which a tool is sought as part of the solution, the decoupling of basic need and satisfaction, and, thus, the independent existence of tools, turns this way of thinking upside down, for tool users instead start with the solution and look for new problems to which they can apply it. In addition, the modular way of handling tools enables the combination of several modules side by side or in an effective chain, thus allowing a level of behavioral complexity – for example, in complex tools such as spears with hafted projectile points – that is hardly conceivable without the modular simplification.

## Conclusions

Problem–solution distance has been identified as a single cognitive factor allowing comparisons of all kinds of animal tool behavior and hominin

artifacts. This factor is basic to tools and tool behavior in general, independent of what needs are met, what material is used to solve a problem, or what other faculties the tool-using or tool-producing species possesses. To compare the problem–solution distance of different tool behaviors, cognigrams are developed as an analytical tool. Based on the principle of *chaînes opératoires*, cognigrams identify the different active and passive foci within an operational sequence, the underlying perceptions, the single-action steps, the effects of one focus on another, and the phases of the sequence. To compare the complexity of different tool behaviors, it is critical to compare the complete distances between the underlying problem and its final solution. Therefore, a thought-and-action process is always started by a basic need and culminated by the positive or negative satisfaction of this need. Four examples of tool behavior have been coded in cognigrams, three of which – the opening of nuts with a hammerstone by chimpanzees, the manufacture and use of an Oldowan stone tool, and the manufacture and use of a trimmed stick to spear lesser bushbabies, again by chimpanzees – show minor differences, especially in the number of foci involved and the length of the effective chain. The fourth example, the manufacture and use of a Lower Palaeolithic spear, proved to be far more complex than assumed. To think a (not so) simple spear, like those from Schöningen, is possible only by decoupling need and satisfaction, so that small action units with intermediate aims can be created and then put together in a modular way. This modification of cognitive processes in tool behavior opens the way for a vast expansion of the problem–solution distance and thus of solutions, as well as problems, unknowable before.

## Long-term memory and Middle Pleistocene “Mysterians”

*Michael J. Walker*

In the long term we are all dead. Alas, dead men’s skulls tell no tales about their brains. Therefore, we ignore at our peril scientific information gleaned from the living about how our brains works nowadays. Yet, they were not always thus. For the past, palaeoanthropology and Palaeolithic archaeology can inform us about hominin cognition. The matter of linguistic evolution cuts across both present and past inferences, and it complicates comparisons not only between humans and other primates, but also between ancient hominins and us. Constrained by the limitations of my allotted length in this chapter, I shall address a single question: How did evolving language impinge on the evolution of long-term memory (LTM)?

Regarding neuroimaging, it has been said that a “problem with human experiments is the potential for people to recode visuospatial stimuli verbally . . . converting an object task . . . into a verbal one” (Fletcher & Henson 2001, 859). Did inadequate verbal encoding of such stimuli hamper consideration of choices about embarking on, and engaging in, chains of activity that comprise sequential links, each of which involves behavior different from that of both the previous and subsequent link? Perhaps protolanguage was simply not up to the task. Maybe, though, verbal recoding depended on demographical density, such that verbal encoding came to act as a proxy for behavior only after a threshold level of social intercourse had been reached; until then, so to speak, there were not enough people to talk to and there was not enough to talk about. Both possibilities might have occurred at different times and places. They could provide an accommodative justification of why Palaeolithic technological evolution was slow to develop. Matters are complicated because pride of place is usually given to phonological

long-term memory (LTM), which is more amenable than visuospatial LTM to neuroimaging research.

It has been inferred that an Early Quaternary hominin quite likely interacted with 100 people, given a positive correlation between group size and brain size in monkeys and apes (Aiello & Dunbar 1993). Such social groupings were probably spread widely over the landscape, but made up of several small ecological groups within which individuals spent most of their time (Dunbar 2000). Nevertheless, it does not follow that social groups must have had some primitive form of language (Martin 1998), even if their members had a “theory of mind” to facilitate social interaction.

Manual skills can be learned by silent imitation, and the role of speech and protolanguage in knapping stone artifacts (or making wooden ones) may have less to do with how knapping is performed than with what is wanted, why it should be done, and where and when to do it – and if it should be done at all. These questions imply an ability to juggle with different matters and ideas, and attend to particular aspects of individual matters. This is made easier if they can be conceptualized separately, and broken down, or built up, in arguments that can be communicated symbolically to other people by word of mouth (cf. Deacon 1997).

### **Logicomathematical appreciation, formal combinativity, and visuospatial appreciation of symmetries in stone knapping**

Two interrelated questions have attracted much attention, although, archaeologically speaking, they are more of a distraction. One is whether an alleged artifact form represents a “mental template” (of Palaeolithic “Mysterians”). Another, more technical, is whether there is similarity in the ways immature apes and humans acquire appreciation of combinativity during cognitive development. “No” is the short answer to both questions. The two questions underlie a third – undoubtedly of archaeological and palaeoanthropological relevance – which is this: Just what may be inferred from regular irregularities and irregular regularities in artifact form? Unfortunately, a concern with this matter by some specialists has led them in advance to presume what surely scientific inquiry ought to have established as a starting point, namely, that those aspects can only be interpreted by answering “yes” to one or both of the previous questions. This has led, needlessly, to muddle-headedness. Let us very briefly see why. Happily, the matter is less complicated than it seems to be at first sight.

A widely held conjecture is that, before the Late Middle and Late Pleistocene, hominin cognition did not resort to fully declarative, abstract planning (for which language is assumed to be a prerequisite), even though, by the onset of the Quaternary period, there are traces of “preoperational” behavioral development (by reference to Piaget’s stages of children’s psychological development, in which preoperational thinking involves mental representation and language) that was more complex than that of great apes, whose rudimentary capacity for planning can nevertheless embrace strategic representation of multiple goals (cf. Parker & Milbrath 1993). However, is hominin cognitive evolution commensurable with the sequence of psychological development of modern children, let alone comparable to it? Whereas nonhuman anthropoids show very slow development of logical planning from a stage of physical responses characterized by rudimentary signaling, in human infants, physical and logical domains of cognition develop together in recursive fashion very early in life, such that second-order cognition is well established by the time the child is 2 years of age, including reversibility and substitution when the child is playfully manipulating nonrepresentational objects (Langer 1986, 2000).

This logicomathematical appreciation of combinativity is present in human infants before they can talk. Even if they can understand some things that are said to them, they are unlikely to have recoded visuospatial stimuli into silent “mentalese” verbal symbols before their responses get recorded. Far from language being a prerequisite for such appreciation, logicomathematical cognition seems likely to be a prerequisite for acquisition of language by very young children. In apes, even rudimentary attainment of logicomathematical cognition is barely reached by 5 years of age, unless there is intervention by human handlers. If it is to be argued that the evolution of a baby’s attainment of logicomathematical cognition was consequent on prior evolution of speech in older individuals, then first appearance of speech has to be interpreted less in parsimonious orthodox Darwinian terms of gradual natural selection than as an evolutionary discontinuity – maybe a genetic anomaly by which a mutation gave rise to a “hopeful monster” of a new chatterbox species in Africa, namely *Homo sapiens*. Langer’s notion of a logicomathematical appreciation of combinativity in young infants is perfectly compatible with notions of the part played by analogical reasoning in the development of Palaeolithic technical invention (de Beaune, this volume) and of the role of symmetries in early Palaeolithic stone knapping (Wynn 2000).

Wynn's "constellations" of knowledge, which imply reversibility, underpinned the Palaeolithic knapping undertaken to fashion blanks or remove and even modify flakes (Wynn 1993). A fuzzy view of "mental templates" looks very like these "constellations" – accurate as regards my needs and wants, rather than a precise protocol of how to attain them. Here is a modern analogy (courtesy of my philosopher friend Ian Herbertson). If I have a new suit and shirt, I may well decide that I want a new tie to go with these new clothes, but not have a clear idea of what style of tie I want. I may think about this and come to some conclusion, but I may not have a clear idea yet still know, once I am inside the tie shop, that the one I see is the one that will go with the suit and shirt. White and Thomas' (1972) observations on modern knappers and bystanders in Papua New Guinea are congruent with that fuzzy view of a mental template – accurate as regards my needs and wants, rather than a precise protocol of how to attain them. Maybe a knapping plan is more like planning a country stroll for one's family than planning a route march with military precision. If that is so, then formal Palaeolithic taxonomical categories cannot be taken, in simplistically reductionist fashion, as reflecting separable categories in hominin understanding, let alone as defining aspects of its evolution that are allegedly represented in ancient Quaternary assemblages.

Although Wynn's constellations of knowledge say little about Palaeolithic language, he pointed out (Wynn 1993) that this does not necessarily imply that stone products could never have been regarded as signifying an indexical relationship in some contexts (cf. Deacon 1997). Plausibly, some circumscribed assemblages of ancient Palaeolithic artifacts were products of one or very few individuals, or, in other cases, were products of populations (societies or communities) with particular traditions or tendencies of stone knapping. Some exercises in complex statistical analysis of so-called Acheulian bifaces have pointed toward such possibilities (among many publications, the following are a representative sample of a wide range: Roe 1968; Wynn & Tierson 1990; Crompton & Gowlett 1993; White 1998b; Ashton & White 2003; Gowlett & Hounsell 2004). Interpretation of results has invoked, variously, differences in tradition, raw material, function, or extent of reduction.

### **Cognition versus recognition**

The variety of Palaeolithic techniques, recognized in the East African Early Pleistocene, implies an element of thinking ahead, comparable with that

involved in the Levallois technology of Middle Pleistocene Europe, according to Roe (personal communication, 2006). Inferences have been drawn about hominin cognition from the coexistence in the later Oldowan of both chopping tools and bifacial tools (Gowlett 1986). Even if Oldowan chopping tools barely exceeded the cognitive capability of great apes (Wynn & McGrew 1989), it has been argued that symmetrical handaxes imply “spatiotemporal substitution and symmetry operations” that are more complex, cognitively speaking, than are “the spatial concepts necessary to manufacture blades” (Wynn 1979, 385). They involve envisaging shapes and volumes from alternative perspectives, rotated in the mind, while paying attention to congruence (Wynn 2000). These aspects seem to be congruent with some considerations about the nature and development of human consciousness, and, in particular, Antonio Damasio’s somatic marker hypothesis as a substrate for the evolutionary development of subjective self-awareness – and quite likely a theory of mind – even before language speeded up recursive spiraling of human culture (for a popular account, see Damasio 1994).

It could well be argued that such a model is by no means incompatible with differently based proposals about what loosely might be called the virtual reality of human thought experiences (cf. Dennett 1991; Deacon 1997; Pinker 1997), for which fully fledged language need not have been a precondition. The matter of self-awareness in Quaternary hominins will be mentioned again in subsequent text, both with regard to knapping and also to making choices between alternative chains of behavior. Thomas Wynn regards handaxes, in particular, as exemplifying evolution of constellations of behavioral plans of action that involve feature correspondence as well as the complex cognitive skill of reversibility, which, nevertheless, could well have been learned and communicated by simply observing and copying, without need for symbolical linguistic assistance, while not excluding a possibility of an indexical role for some artifacts (Wynn 1993, 1995).

A sceptical rejection of cognitive implications drawn from handaxes dismisses them as a “finished artifact fallacy,” self-servingly reflecting archaeologists’ predetermined categories – such as handaxes, Levallois blanks, and the like – for defining those objects considered worthy of interest to study (Davidson & Noble 1993; Noble & Davidson 1996). However, the force of this rejection rests, insecurely, on just how far individual hominins “intended,” or not, to produce mainly (or only) those particular by-products of behavior that coincide with only (or mainly) those artifacts on which archaeologists confer distinctive typological names. Two separate matters have become unnecessarily intertwined here: Namely, the analytical

classificatory recognition of taxonomists on the one hand, and whether that might or might not reflect intentional cognition in Palaeolithic behavior on the other.

Taxonomy uses an eliminatory analytical methodology to separate and recognize nonidentical things in an exclusive fashion. This does not imply that somehow carbon-14 with atomic weight 14 is somehow less carbon-like than is carbon of atomic weight 12, or that *Pan paniscus* is somehow less chimpanzee-like than is *Pan troglodytes*. The reason is simple. It is because analytical taxonomy can order nonidentical things only in terms of only those similarities or differences for which a particular eliminatory methodology was designed. Atomic numbers separate carbon from silicon, and chromosomal numbers separate chimpanzees from human beings.

Taxonomies help us to order nonidentical things and to infer possible structural relations between them. However, these inferences may differ, depending on the methodology used – and also on the choice of non-identical things to study: this latter aspect is relevant here. Fifty years ago, specific separation of *Pan paniscus* from *Pan troglodytes* was regarded more as a conjectural possibility than as being a well-defined scientific working hypothesis that had withstood attempts to falsify it. But, let us beware. Molecular genetics suggests that the two species separated not much before the onset of the Quaternary period. Evolution is a dynamic concept about nonidentity (descent with modification by means of natural selection), not a static one. Would we really have recognized what seems quite likely to have evolved, were we to have gone on regarding them all, in undifferentiated fashion, as “just chimps,” no more and no less?

Put another way, by picking away at differences, sometimes it may just be possible to propose their separation in terms of spatiotemporal chains – but only, of course, as a working hypothesis open to refutation. That refutation may involve showing that bonobos and common chimps are but one species, or that handaxes and Levallois blanks are all much of a muchness in a more general context of nondescript flake production or mere rock smashing; we shall return to this aspect later on. It is worth remarking that formal taxonomy need bear no relationship to the cognition of participants. Thus, at some places in the New Guinea Highlands, neither knappers nor other members of their community invariably agree on how to name knapped stone artifacts, and those names by no means always correspond to exclusive taxonomical categories, as defined in terms of the formal characteristics of the artifacts knapped (White & Thomas 1972): This shows that

formal taxonomy need not imply a strong correlation between a knapper’s intention with regard either to future use of artifacts or their form, nor yet how bystanders choose to name and use them (much less, that taxonomical names have to be scientifically descriptive: *Pan troglodytes* is clearly not, nor are words such as *Acheulian*, *Levalloisian*, or *Mousterian* – which is an exemplary reason for using them).

This does not mean, though, that the taxonomy of Palaeolithic artifacts is unable to point toward matters of interest, taking due precautions, at the much coarser-grained Pleistocene spatiotemporal level. Of course, different or alternative classificatory systems can be constructed, depending on the questions to be addressed. Questions about Palaeolithic cognition have as yet to form the basis of a workable Palaeolithic taxonomical system.

It is quite plausible that those artifacts that particularly have aroused the “interest” of archaeologists were outcomes of chains of activities, involving often more than one actor, from searching for and retrieving raw materials (whether close to hand or further afield), to knapping processes that went beyond a single knapper’s *chaîne opératoire* and extended to use (edge-damage microscars), and refashioning at a later time (patinated flakes were reworked sometimes at Cueva Negra del Estrecho del Río Quípar, as at many Pleistocene sites). Maybe, therefore, intentionality should be interpreted less in terms of a single individual’s fully self-aware intentions and more, by reference to evolutionary biology, as results and by-products of deterministic chains of complex activities that afforded tried-and-tested adaptive value to evolving hominin populations (societies or communities? – perhaps these words imply more than we have a right to infer) that as yet possessed only an emergent cognitive capability that was unspoken and unconscious, not yet self-aware or spoken aloud, although perhaps this itself might have been an exaptation that reflected the co-opting of brain circuitry, which similarly may well have enabled dispersal of social groups of Plio-Pleistocene hominins (cf. Gamble 1993, 99, 111).

As Wynn (1995, 21) put it, “it would be difficult to overemphasize just how strange the handaxe is . . . it does not fit easily into our understanding of what tools are, and its makers do not fit easily into our understanding of what humans are.” It is also worth bearing the matter in mind when considering Levallois cores; thus, Noble and Davidson (1996, 200) remarked that whereas the “standard interpretation is that a core was prepared in such a way that a flake of predetermined shape could be removed . . . it does not seem likely that such cores represented a novelty in planning beginning at

the time the Levalloisian technique is said to appear. Rather, such cores had been used for producing flakes almost from the very beginning, and continued to be so used even after knappers began to strike large flakes from them.”

### **Cognogenesis and alternative behavioral chains: When did language become relevant?**

Advances in rigorous multivariate statistical methodology applied to numerical taxonomy and spatial analysis have led to a reconsideration of findings that had been deployed in support of some interpretations (McPherron 1999, 2000) – although it seems quite possible that there is no single, one-size-fits-all interpretation of handaxes. This is not the place for yet another review of a very wide-ranging topic, both because some matters are still unresolved and, what is more important, because several of them refer to finer-grained aspects of the hominin record than the coarse-grained matter in hand – the alternative behavioral choices that were made by some hominins during the Early-to-Middle Palaeolithic transition in Western Europe. How did these arise? What do they imply for cognogenesis and the evolution of hominin consciousness in the Middle Pleistocene? Did most Middle Pleistocene hominins in Africa and Europe possess similar capabilities?

Wynn (2000, 138) remarked on a paradox: “by 300,000 years ago spatial perceptual-cognitive thinking was modern. The ability to conceive and execute regular three-dimensional congruent symmetries in flaked stone was in place. . . . Despite having a repertoire of modern spatial abilities, these hominids did not produce modern culture.”

Perhaps there should be less emphasis on the cognition and skill of individual hominin stone knappers. An alternative is to consider the archaeological record as showing that hominins made choices – spoken or unspoken – that required decisions – spoken or unspoken – to be taken about embarking on, and engaging in, chains of activity that comprise sequential links, each of which involves behavior different from that of both the previous and subsequent link – sometimes involving different actors, perhaps separated in time by many generations.

At Cueva Negra del Estrecho del Río Quípar, *Homo heidelbergensis* by 0.5 million years ago was able to choose between different ways of modifying stone (Walker et al. 2006). Although most of the behavior may have been

silent and imitative, protolanguage may have been required for making and taking choices – which chain to take part in, what is wanted, why it should be done, and where and when to do it – and if it should be done at all.

Did the Cueva Negra hominins, so to speak, enjoy an edge over Nature in a singular microenvironment? Is it too much to wonder whether that slight edge provided beneficial circumstances within which alternative Palaeolithic working edges came to be knapped? Can this be inferred from the flexibility with which hominins were able to execute the very different chains of behavioral activities involved in the bifacial fashioning of a limestone cobble into a handaxe on the one hand, and the Levalloisian knapping of flakes from prepared chert blanks on the other?

Perhaps the plan-like principles that set out those different practical objectives, which must have been held in mind as separate and alternative possibilities, while at the same time letting the knapper monitor the chosen work in hand so as to allow its transformation in a fluid yet structured configuration of possibilities according to the initial choice of objective, imply that working memory was not held in an iron grip by a single expert aptitude in procedural LTM but, instead, could pick and choose from very different alternatives stored in LTM. Did these choices mean that alternative patterns of behavior had sometimes to be explained verbally to bystanders? Did they come back with, “What if you were to have chosen to make a handaxe instead of a Levalloisian flake?”

The facilitative part that language could have played raises a question of whether fluency might have increased as human populations increased. Selection pressure for fluency could have been an outcome of exponentially increasing interactions between growing numbers of people. In those Palaeolithic communities that experienced the greatest demographical abundance, an acceleration in rate and frequency of interpersonal discourse could have led to positive feedback, in nonlinear fashion, with cascade effects. The outcome was modern culture.

Maybe labeling some assemblages as “Mousterian” reflects growing demographical abundance and density of knappers from later Middle Pleistocene time onward. Perhaps one that would be followed was a growing tendency toward debitage assemblages, and toward their production governed by secant-plane techniques, perception of which could have gone hand in hand with neuroanatomical exaptations in brain circuitry favoring nonlinear evolution, in self-organizing manner, in larger-brained, later Middle and Early Late Pleistocene hominins. If natural selection came

into play at both biological and behavioral levels, advantages accruing from debitage assemblages such as those of the Mousterian and African Middle Stone Age could have permitted growing demographical abundance and density of hominin communities in Africa, Southwestern Asia, and Europe.

The likelihood that the Middle Pleistocene record affords empirical evidence that hominins participated in self-determining or self-constraining chains of sequential behavioral activities, which permitted alternatives open to freedom of choice and thus enabled second-order cognitions, is a working hypothesis about a peculiarly palaeoanthropological approach to cognitive evolution. The very limitations of the approach endow the hypothesis with the advantage that it is open to the possibility of refutation (falsification) by future research into the material record to which it is addressed.

## CHAPTER 8

### **The quest for a common semantics: Observations on definitional criteria of cognitive processes in prehistory**

*Carolina Maestro and Carmine Collina*

In this chapter, we introduce some methodological questions about the application of a cognitive approach to prehistoric archaeological evidence. On the one hand, our aim is to encourage a methodological reflection on the terminology and the concepts adopted in the studies on the evolution of cognitive skills. On the other hand, our aim is to outline the need for a better definition of the role of the lithic technology in the interdisciplinary debate about elaboration and transmission of knowledge.

At an early stage we moved from a key question: Can an archaeologist, a specialist of material cultures, master the epistemological tools of the cognitive sciences and apply them to prehistory, especially to the most ancient periods? The study of cognitive processes requires the participation of scholars with different research backgrounds. Therefore, we can reverse the question, asking whether a specialist of cognitive activities would be able to manage the theoretical and technical tools linked to analyses of material culture, to avoid generalist approaches to the evolution of human activities and the technical structures implied by the lithic technocomplexes.

Heuristic approaches generally share the overlap of two cognitive interplaying dynamics: “subjectivation” (individual cognition) and social sharing. These dynamics are theorized in the domain of mental and social processes and are applicable in the sphere of material evidence. The first notion is the process whereby knowledge is acquired and processed. The second one represents the dynamics whereby knowledge is structured, tested, evaluated, and transmitted.

The history of cognitive applications in prehistory is essentially characterized by two fundamental research lines. The first is the analytical pattern proposed by Jean Piaget in which cognitive development follows a series of

stages, derived from developmental psychology. The second is the concept of modularity, mainly theorized by J. Fodor (1983). From this point of view, the mind is structured according to a specific tripartite architecture organized in modules. These modules are genetically determined: Each one covers a specific field and is located in a particular region of the brain. Fodor's analyses (1983, 2000) of the "inputs" deal with the vertical structures, whose function is to mediate between the output of the perception organs and the central systems. It is a system devoted to more complex elaborations. The process of transforming the inputs into representations implies patterns of a computational mind.

Several cognitive researchers (Donald 1991, 1998; Carruthers & Chamberlain 2000; Samuels 2000; Wynn 2000, 2002; Coolidge & Wynn 2001, 2005) have developed theories of cognitive evolution based on the notions of modularity and emergent cognitive architecture. Particularly, Donald has underlined the concepts for a cognitive classification of hominid culture. As he puts it, "cognition and culture are in many ways mirror images, especially in the human case" (Donald 1998, 11). Making use of cognitive criteria, he has theorized successive stages in the evolution of hominid culture, and he has proposed that each stage "persists" (1998, 14) in the next one. Accordingly, the main feature of evolution is continuity in the increasing cultural complexity marked by cognitive "layers." The last cognitive stage of humankind is characterized by the layering of the previous stages.

Such approaches deserve attention because they propose complex evolution dynamics overcoming the limits of the patterns of linear evolution. However, the variability of Palaeolithic material cultures, particularly of the technical systems carried out, is not completely addressed. For the archaeologists, the study of material culture is based on the observation of empirically concise phenomena responding to specific tasks and skills or, more properly, the socioeconomic structure. Their logic and functional sequences allow a more complex evaluation of the cultural process. In contrast, psychologists and other cognitive researchers are more prone to emphasize general dynamics over long-term periods and to find structural "meanings" and classifications of the cultural behaviors.

## The questions

Approaching the domain of cognitive evolution, it is possible that archaeologists do not attain a mastery of the fundamental terms and meanings

of the cognitive sciences. Furthermore, it is possible that specialists of the cognitive approach do not fully explain the actual meanings or control the particular dynamics generated by the material culture, particularly by the technical structures implied by lithic assemblages. The literature of the various disciplines (anthropological approach *sensu lato*, cognitive approach), seems to suggest that the main obstacles to a correct epistemology are characterized by a lack of transversal terminology and by the difficulty in establishing a correct bi-univocal communication value between the various methods, that is, one meaning among many disciplines.

Our observations derive from some “simple” questions:

- What are the terms framing a cognitive process in prehistory?
- What are the cognitive indices of major or minor complexity of technical behaviors?
- What is the contribution of the cognitive sciences?
- What is the task or tasks of lithic technology?
- How should the question of cultural transmission during the Palaeolithic period be addressed?
- Is the technological approach adequate to appreciate know-how and concepts?
- Is it possible to shift from the definition of particular to general frameworks and vice versa?

We will try to answer these questions, indicating the possible heuristic paths and their epistemological constraints.

### **Searching for the intentionality: The heuristic choices**

Starting from the lithic industries of the Oldowan, Lower Palaeolithic or Early Stone Age, and the Middle Palaeolithic or Middle Stone Age up to the more recent periods of the Palaeolithic era and prehistory, research on the cognitive domain aims to identify levels of intentionality, that is to say, the mental choices generating technical production. At different levels, cognitive and technological approaches tackle the aforementioned issue (Roche et al. 1999). Therefore, it is necessary to establish criteria to recognize biomechanical skills, eventual capacities of abstraction, and the reproduction of shapes. The analysis of a single lithic object can provide empirical information to investigate the skills and cognitive capacities embedded in the knapping process. Likewise, a synoptic evaluation of

lithic objects may identify elements of social transmission, conservation, and innovation of the techniques and the know-how. The generalization (long-term research) of the cognitive approach per se can not account for the variability in technical behaviors. The adoption of psychological categories may pay little attention to specific features of Palaeolithic technical processes that are not often explicable in evolutionary terms. For example, in the shaping of a handaxe, does the choice of a technique, a gesture, or even a hammer represent a cognitive variable? Is this variable actually considered in the framework of a long-term explanation?

The technological approach, in contrast, seeks the reconstruction of reduction sequences, defining the technical strategies and gestures. It also seeks the identification of the economy of debitage of a lithic complex, recognizing the choices correlated to social needs. Nonetheless, lacking the support of neuropsychological and anthropological explanations, such an approach may not properly address the mental structures and the competences implied in the decipherable performances. In other words, to shift from the empirical level of the observation of the lithic objects to the mental domain of the so-called planning and the reduction patterns, it is indispensable to evoke neuropsychological concepts and to search for regularities. For example, the concept of *savoir faire* is linked to various predetermined capacities that are not discerned without the support of analogical processes between archaeological performance and neuropsychological notions of competence.

### **Cognitive process and the actions observable in prehistorical contexts**

Borrowing one of the psychological definitions (Fodor 1983; Calabretta 2002; Calabretta & Parisi 2005), we will elucidate the main features of a cognitive process and the kind of actions applicable to prehistoric contexts. A cognitive process is the sequence of specific events that are needed to structure all types of knowledge. In this process, the subjects are autonomous entities having intentionality and that interplay with the material world and the “mind.” The main mechanisms embedded in a cognitive process are the skills of perception, vision, memory, and reproduction. These skills interplay with the environment and with raw materials, and they are shared with a social group. In a cognitive process, many different kinds of interaction between the mind-set and the external surroundings may allow for the elaboration of symbols.

The cognitive process is a by-product of the brain. This process implies activities of actions on different and interrelated levels:

- From the point of view of the individual, it is possible to isolate the capacity to elaborate information by cognitive mechanisms structured in our brain.
- Cognitive activity is not exclusively characterized by these internal mechanisms. It finds its way through the brain and the environment. Accordingly, the artifacts represent the external performance of internal dynamics and the outputs of the mental conditions.
- The cognitive approach is characterized by specific activities of transmission and acquisitions of different kinds of knowledge, implying a dynamic system for exchanging of information.

Many mechanisms of cognitive action are identifiable in the relationship between individual and object: the perception of the object; the definition and the evaluation of its function; its utilization (appropriation); and its abandonment or replacement. These elements of the cognitive process are useful to prehistorians, but the anecdotal evidence of the archaeological record does not allow us to define the context in which the cognitive actions take place.

### *Epistemological limits of the cognitive approach in prehistory*

Behind the obviousness of the modularity of complex organisms, several authors (e.g., Barkow et al. 1992; Nolfi 1997; Calabretta 2002) pose important questions: What are the advantages of a modular organization in comparison with a nonmodular organization? What are the mechanisms encouraging the evolutionary emergence of modularity? What are the mechanisms deterring this emergence? Are these mechanisms the same for all the modules? Could the genesis of modularity in the brain differ from that of other organs?

From various theoretical points of views, several disciplines, such as biology, the neurosciences, and the cognitive sciences, try to answer these questions. A weak interdisciplinary approach may represent a great obstacle to the study of modularity. In prehistory, one of the potential limits of the cognitive approach is that it might not yield a complete view of the phenomenon in question. An epistemological limit is represented by the difficulty in making the perception of the interaction between the brain

and the environment dynamic. In addition, the idea of a linear evolution of cognitive capacities does not suit the observation of the variability of Palaeolithic industries.

For example, some cognitive studies on the evolution of the lithic industries offer a generalist vision of the techniques and the methods employed by prehistoric people. These studies neglect technological notions such as the “techno-cultural polymorphism of the Palaeolithic” proposed by Boëda (2001, 28; also see Boëda 1991, 2005). According to his hypothesis, the concept of “complexity” in prehistory is affected by a chronological vision based on development processes having a more or less linear nature. However, a detailed analysis of methods and technical procedures shows that lithic objects are the output of stable and well-structured technical systems. In this view, different kinds of methods and knowledge may appear in the same evolutionary stage. The chronological scale is the frame of the technical behaviors, but it is not a compulsory condition for the increase of technical skills. As proposed by Boëda (2001, 6), the production of a blade is not automatically more complex than that of a handaxe. However, the cognitive approach may contain a fundamental heuristic limit: the difficulty to perceive the epistemological detail of the technological analysis.

### Lithic technology and the *chaîne opératoire* approach

Several researchers have been concerned with providing a theoretical background to the technological approach since its first introduction (Leroi-Gourhan 1943, 1964; Bordes 1947; Tixier et al. 1980; Pelegrin 1985, 1990, 2000; Pigeot 1987, 1991; Geneste 1991; Perlès 1991; Sigaut 1991; Soressi & Geneste 2006). The scientific literature has been mostly oriented toward offering an analytical tool. The lithic technology approach, through the *chaîne opératoire* concept, places the lithic object in a hierarchical line of genesis, explaining “how” and “when” (in a specific spatial development) its production occurred (Pelegrin et al. 1988). A *chaîne opératoire* consists of three elements (see Table 8.1): the knapped-stone objects, related to different phases of the debitage sequence and of the operational project (acquisition of the raw material, the initial shaping out of the core, the core reduction, the production of tools, and utilization and abandonment); the behavioral sequence that produces the artifacts and determines the initial interaction with the environment; and the specific knowledge possessed by the knapper. Thus, the technological data are set in a landscape perspective

TABLE 8.1. A synthetic scheme of the chaîne opératoire approach with the analytical steps identified by various authors

The theoretical stages	The analysis levels
<b>1. Conceptual schema</b> <i>Predetermination</i> <i>Competences</i> <i>Savoir faire</i>	<b>1. The technical objects</b> <i>Products of the knapping activity</i>
<b>2. Operational schema</b> <ul style="list-style-type: none"> <li>● <i>Raw material provisioning</i> Acquisition strategies</li> <li>● <i>Production</i> Methods, techniques, strategies (technical behaviors that produce the lithic assemblages)</li> <li>● <i>Utilization</i> Function and functioning of the tools</li> <li>● <i>Abandonment</i> <i>Relationship with the socioeconomic needs</i></li> </ul>	<b>2. The sequence of the gestures</b> <ul style="list-style-type: none"> <li>● <i>Technical gestures–procedures</i></li> <li>● <i>Relationship time–space</i> “where” and “when” of the production process Context of abandonment</li> </ul>
	<b>3. Savoir faire</b> <ul style="list-style-type: none"> <li>● <i>Technical skills–Predetermination of a conceptual planning</i> Structural reasons of the production process Research of the competences</li> </ul>

*Note:* The various authors are Tixier et al. (1980), Pelegrin et al. (1988), and (Pigeot 1987, 1991). On the left of the table, we propose the conceptual and theoretical phases by which the operational process is predicted and realized. On the right, there are the corresponding levels of analysis allowing the reconstruction of the reduction process.

surrounding both the territorial dispersion of the operational sequences and the management of the raw material sources.

The chaîne opératoire tool has allowed us to obtain a great deal of qualitative and empirical information. The analytical criteria derived from this methodology allow the exploration of the gestures and types of hammers used to fracture rocks. Furthermore, their effects on raw material and uncontrolled knapping accidents have been recognized (Crabtree 1972; Callahan 1979; Tixier et al. 1980; Pelegrin 2000). Debitage processes have been reconstructed by experimentation on raw materials used by prehistoric people and by refitting archaeological pieces.

The cognitive implications of the hierarchical organization of the knapping operations have been addressed especially by Pelegrin (1985, 1995, 2005). Technology prompts the evaluation of the cognitive context of prehistoric humankind (Roche 2005). The lithic objects have technical value in the modalities of production and in the choices realized, from

the selection of raw materials up to the transformations giving the final stage of the tools (Séris 1994; Boëda 2005). Any understanding of the knowledge behind these technical values implies an analysis of the reasons that determine the acquisition process. Each object is set in a network of knowledge and competences that are structured and represented in “technical systems” (Geneste 1991; Pigeot 1991). Lithic technology attempts to explore and decipher these relational networks to find the logic and “coherence” (Boëda 2001: 13) in the lithic assemblages (Simondon 1958; Deforge 1994). In other words, the epistemology of the technological approach consists of two phases: The understanding of the technical heritage of the lithic pieces and the perception of the modifications of the technical systems. This allows the development of an evolutionary model of the techniques (Boëda 2005) and of the mental patterns (See Table 8.1).

#### *Epistemological limits of the lithic technology approach*

Therefore, the heuristic procedures of a structural technological approach, based on the concept of *chaîne opératoire*, focus the lithic objects in a synoptic vision that sets the lithic assemblages in landscape and systemic perspectives. Nonetheless, the cognitive perspective is still difficult to address. The terms *savoir faire*, *operational scheme*, and *project* may generate an epistemological ambiguity. The actual nature of the cognitive process is explained by reference to circumstances not given by the lithic objects themselves. It is difficult to explain the competences supporting the empirical data of the artifacts: Is *savoir faire* a synonym of knowledge? In what sense is it possible to speak of knowledge structuring? What is the relation to the cognitive concept of layered stages of knowledge? Is the operational planning really the output of a predicted representation? How is the “project” linked to conceptual forms of nature?

The epistemological limits of the technological approach are represented by the difficulty in identifying the reasons and the circumstances determining the concept of a reduction process and a tool. Different levels of knowledge, competence, manual skills, and transmission are also implied. The technological approach is able to perceive these suggestions describing the coherence of a lithic assemblage, but it is not able to codify a complete epistemology because of the lack of references for the mental levels of cognition.

### Final considerations: Searching for a common semantics

In light of the points made herein about the possible approaches to the study of the cognitive process linked to the lithic industries, we propose some general considerations.

First of all, the analysis of lithic objects, from an economic and operational point of view, allows for the definition of the technical systems. The analysis of mental structures represents a level of analysis based on the explanation of the operational processes. These are realized by the interaction between humans and raw material. Nevertheless, the path from the structural level of the systems to the cognitive ones requires an indispensable reformulation of the semantics. The reconsideration of the approaches may give rise to the creation of a specific methodology that cannot ignore the necessity of pointing out the variability in technical-cognitive structures of Palaeolithic assemblages.

In a same assemblage or in contemporary assemblages, lithic technology may identify the gestures and the strategies distinguishing the difference between the management of methods and the capacity of control over the techniques. This distinction is a key element in the study of the cognitive abilities and the skills. Nevertheless, we observe the same difficulty: Cognitive approaches are not able to perceive the level of detail of the technical procedures whereas a technological approach does not decipher the “contrast” between the object and the cognitive circumstances that generated it.

In summary, the heuristic dichotomy between the different approaches is based on three observations, above all:

1. Although the lithic technology alone is able to explain the development of a production process, it does not explain the aspects connected to the “conception” of the process itself.
2. The notion of *savoir faire* does not distinguish between technical abilities and the mastery of gestures and conceptual capacities.
3. Cognitive approaches often do not consider aspects connected with the material development of the operative process and with the variability of methods in the same evolutionary context. The cognitive approach may neglect the phenomenological variety of lithic industries without considering the particular feature of the technical behaviors and the structures of each technical system.

In perspective, an integration of the approaches represents a necessary condition for a prolific research on cognitive abilities and for an actual communication between more or less contiguous disciplines. The creation of a common semantic (for example, the concept of modularity and the concept of choice of production) could encourage this purpose. In this regard, a recent book by Roux and Brill (2005a) collects contributions from archaeologists as well as scholars from other disciplines: neuroscience, psychology, ethology, and science of movement.

The cognitive domain represents an elaborated process of interaction: individual and social, implicit and explicit. Lithic technology, by itself, is not able to provide definitive answers. We would ponder whether cognitive theories can help the archaeologists find those answers.

## CHAPTER 9

# Cognition and the emergence of language: A contribution from lithic technology

*Jacques Pelegrin*

Attempting to understand the development of hominid cognitive capacities based on their technical productions is not a new approach. André Leroi-Gourhan (1964, 1993) laid the foundations in the 1960s when he first proposed the idea of a concomitant evolution of language and techniques based on the proximity and parallelism of the cerebral zones and paths implied in both motor functions and language. At that time, however, the study of prehistoric lithic industries was essentially limited to a typological approach and the inferences thus drawn concerning the mental capacities of their authors were rather general (e.g., Alimen & Goustarid 1962; Bordes 1971).

Several other approaches have since been proposed (e.g., Toth 1993; Wynn 2002). In France, in particular, a new approach to knapped stone artifacts was developed whereby these objects were no longer seen solely as “fossil directors” of periods and cultures, but also as evidence of so-called operational sequences (*chaînes opératoires*) and thus technical (and economic) behaviors. This notion of operational sequence was also introduced by Leroi-Gourhan in 1952 (Schlanger 2004, 2005). Its full potential was then developed through the practical expertise of Bordes and Tixier (Tixier 1967). Tixier then played a major role by systematizing principals of the operational sequence through the “technological reading” of lithic objects, coupled with a stabilized and enriched terminology. In particular, Tixier (1967) proposed the very pertinent distinction between *technique* and *method*, thus distinguishing, respectively, the modes of flake detachment and the organization (spatial and chronological) of the removals during a knapping operation (debitage or flaking, shaping, retouch, preparation; see Inizan et al. 1999).

It is useful to recall these two distinct levels implied in hard stone knapping (knapping being defined as intentional fracturing by conchoidal fracture, other than exceptions). The word *technique* refers to the physical modes of executing flake detachments. They are associated with several parameters: the nature of the application of force (direct percussion, indirect percussion, pressure); the nature and morphology of the knapping tools (hard stone, soft stone, wood billet, etc.); and the manner in which the knapped object is held and the body position of the knapper (on an anvil, other support, freehand, etc.). The word *method* refers to the spatial and chronological organization of the removals from a knapped object. When this organization is repeated in an archaeological assemblage – which is often the case – a knapping method is identifiable. It then corresponds to a procedure that is at least systematized and more or less reasoned.

This distinction between technique and method is also relevant from a methodological point of view. Techniques, on the one hand, are identified through analogical comparison with experimental data (analysis of modern knapping products). This comparison is strengthened by a mechanical understanding of certain stigmata, which are related to certain parameters of the technique. For example, the degree of diffusion or concentration of a point of percussion is directly related to the hardness of the hammer used.

Methods, on the other hand, are identified through a technological reading of all of the archaeological material. A particular method – and its variants – within an operational sequence is “reconstructed” through a synthesis of all observations of the spatial and chronological organization of the flake scars visible on each piece (diacritic scheme).

For readers lacking experience in the study of knapped stone objects, it is also useful to emphasize the excellent so-called visibility of the knapping actions produced on a piece. Knapped stones being nearly inalterable, their technological characteristics (point of origin, dimensions, orientation, and order of preceding removals) are completely, or nearly completely, preserved in a redundant manner. Each removal produces a double equivalent trace: on the object from which the flake was removed (its negative), and the flake itself (its positive). Therefore, a piece shaped by the removal of numerous flakes shows the negative scars of the last series of flakes removed, which are themselves identifiable as such. The same is true for a core and its products. This visibility allows us to associate (and classify) corresponding pieces and, if there are many pieces in an assemblage, to refit them like a puzzle, and thus to totally objectify the method applied.

In this way, by clearly demonstrating that the knapping method(s) identified in a prehistoric industry are related to a “procedure,” Tixier opened the possibility of more psychological analyses – meaning cognitive rather than only descriptive – of the organization of removals from a piece. This introduced the notions of selection, intention, and predetermination, which were then further developed by his followers.

At the same time, this analysis was facilitated by the development of modern, experimental stone knapping under the impetus of Bordes and Tixier, themselves experienced knappers like Crabtree in the United States. Indeed, this type of analysis of knapping methods – once they have been identified on the archaeological material – requires particular competencies. First, it is necessary to have practical knapping experience, which is either direct, by knapping oneself, or indirect, through numerous observations and discussions with a knapper who is preferably an archaeologist. Second, and most importantly, one must have experience with variable archaeological cases.

To illustrate, we can compare a knapping method with the transcription of a game of chess. A chess expert can psychologically analyze a game (or better, a series of games between two players): He or she will be able to evaluate the skill level of the opponents (stereotyped sequences, simple reactions or one or several moves planned in advance), their intentions and priorities (central development, outgoing of pieces, attack, defense), and their knowledge (strategies for opening or closing – and possibly ending – the game). The same is true for the study of stone knapping methods, in which an experienced analyst can recognize stereotyped sequences that may be repeated (simple methods based on monotonous formulas of organization; Pelegrin 1993, 2004, 2005), appreciate different degrees of predetermination (predetermined removal or predetermining removal; cf. Boëda 1994, 1995), or analyze elaborate methods based on planning by objective (Pelegrin 1990, 2005).

Appreciated in this way, prehistoric knapped stones can provide relevant evidence of some of the cognitive capacities of our hominid ancestors. On this basis, we can now address the subject of this chapter,<sup>1</sup> which can

<sup>1</sup> This chapter was translated and corrected by Magen O'Farrell; it includes some passages from an earlier text (Pelegrin 2005), the translation of which was corrected by Marcia-Ann Dobrès, whom I thank. I also thank the editors of this volume: Sophie de Beaune, who invited me to participate, as well as Fred Coolidge and Thomas Wynn. The Master's thesis of Frédérique Bresson (synthesis and references in Bresson 1992) also contributed to this

be formulated by the following question: According to this procedure for analyzing knapping methods, what cognitive capacities can we distinguish in hard stone knapping that could be related to certain prerequisites of language?

A first tempting approach, proposed by some anthropologists and prehistorians, concerns the nature of the transmission of the so-called art of knapping to children. In other words, starting from which stage or method would language have been necessary for elders to explain to young learners what to do and how to do it? This approach is not very convincing because, in general, psychomotor skills are not acquired through verbal instruction. This is true in traditional apprenticeships, and in the case of flint knapping, we know people who have learned to knap without observing a skilled knapper and without documentation. Even if language, once acquired, certainly participated in the technical education of learners, it is not a condition for the transmission of techniques. This approach, which we could call the “short route,” is thus inoperable.

What remains is the “long route,” which consists of identifying the neuropsychological elements in technical productions, at the level of thought and technical reasoning, which may be significant prerequisites of language.

### **The notions of specified intention and skill**

We long considered the oldest stone tools to be the result of sensory-motor actions performed without conscience – meaning two cobbles or pieces of stone, chosen at best for their form, were knocked against one another until one or several fragments were detached and then selected for their cutting edge. However, the recent discovery by H el ene Roche (Roche et al. 1999; Roche 2005) of the Kenyan site of Lokalalei 2C considerably modified this perception. At this site, dated to 2.3 million years ago, around 50 blocks or large fragments of volcanic stone were knapped to obtain flakes by conchoidal fracture. Refittings (replacement of the flakes on their block or original core) show that from one to several dozen flakes were detached from each core. These removals were organized by small, subparallel, or convergent series, at the expense of a favorable morphological configuration,

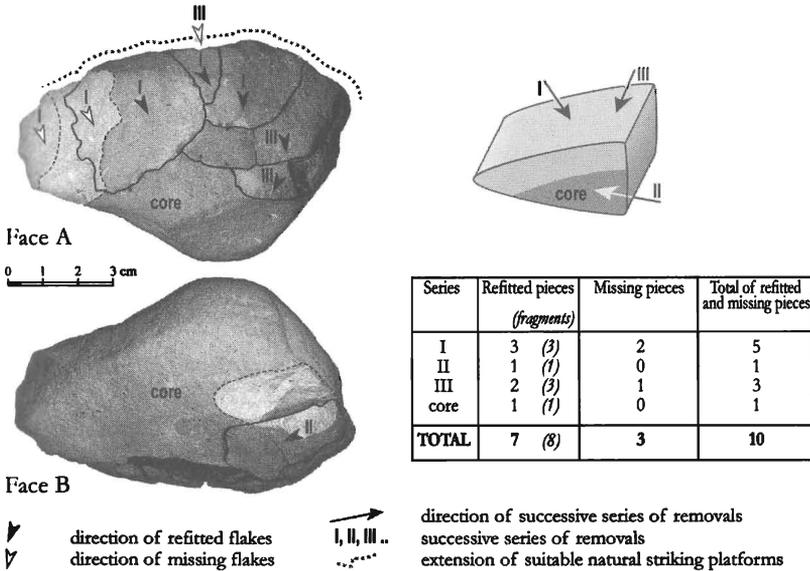


FIGURE 9.1. Photographs and drawing of a refit core and its flakes from Lokalalei 2C, showing the process (I) after five flakes, (II) the removal of a flake to correct the striking platform, and (III) continue the debitage process. (Figure is after Delagnes & Roche 2005; photograph and copyright are from the Mission Préhistorique française au Kenya, director H. Roche, by permission of Hélène Roche.)

meaning a nonobtuse dihedron forming the striking platform on one side and the relatively wide debitage surface on the other.

Although this operational sequence appears globally reducible to a simple formula, that is, “detach a series of adjacent flakes from a favorable dihedron,” several of the cores indicate a more complex process. When the striking platform of these latter cores became inadequate, it was repaired by the removal of a small flake struck from the flaking surface before the principal flaking operation was continued (Figure 9.1). In other words, faced with the inadequacy of the striking platform, the individual was capable of correcting this fault by a removal not intended as a product, but rather adjusted for its effect on the configuration of the striking platform.

We thus see the first evidence of a technical “skill” in stone working (meaning knowledge that goes beyond a simple sensory-motor action), objectified by a true specification of the intention: although the flakes normally removed have the value of potential products, other removals

are conceived for their expected effect on the core. The same elementary action, an adjusted percussion to detach a flake adjusted to the situation, can thus be deliberately performed to satisfy different intentions, which we are tempted to say have different meanings.

We should also emphasize the absence of hammering or useless strikes, which would be easily visible on the material as crushing at impact points. This shows that the knappers did not attempt to detach flakes when the angle was inappropriate, as well as the precision of their strikes, which necessitates knowing where and how to strike and having the ability to do so. Moreover, the lucidity of the author(s) is shown by his or her aptitude to reorient the core to preserve or recreate a morphological configuration combining the striking platform and debitage (flaking) surface.

Before 2 million years ago (by *Homo habilis?*), we are thus tempted to see in this first degree of knapping control (the capacity to improve possibilities, demonstrated by a specific solution) an initial level of what we could call “technical conscience.”

### **The shaping of symmetrical bifaces: Evidence of conceptualized mental images**

The first bifaces (also called handaxes) appear in Africa around 1.7 million years ago. These tools were at least partly shaped to form a point and at least one lateral cutting edge by the removal of flakes (waste products) from each of their two faces. The form of bifaces, which are often found during surface collections and thus impossible to date, seems to become gradually more specific, indicating that they indeed represent a particular tool.

In contrast, the stratified site of Isenya in Kenya (excavated by Roche) has yielded several hundred bifaces, dated to around 700,000 years ago, whose elongated almond shape is repetitive, regular, and symmetrical in both plan and profile view (Figure 9.2). Although their dimensions vary slightly, their form is repeated, demonstrating that their authors had a mental image of this form. Although the numerous shaping removals were adjusted according to a highly variable spatial and chronological organization, the objective was always to produce this preconceived form (Roche & Texier 1996).

Roche had already considered that, during the Acheulean period, we passed from stereotyped actions to stereotyped forms (Roche 1980, 193), which is in agreement with Bordes, who discerned the progressive stabilization of tool forms throughout this long period (Bordes 1970, 199).

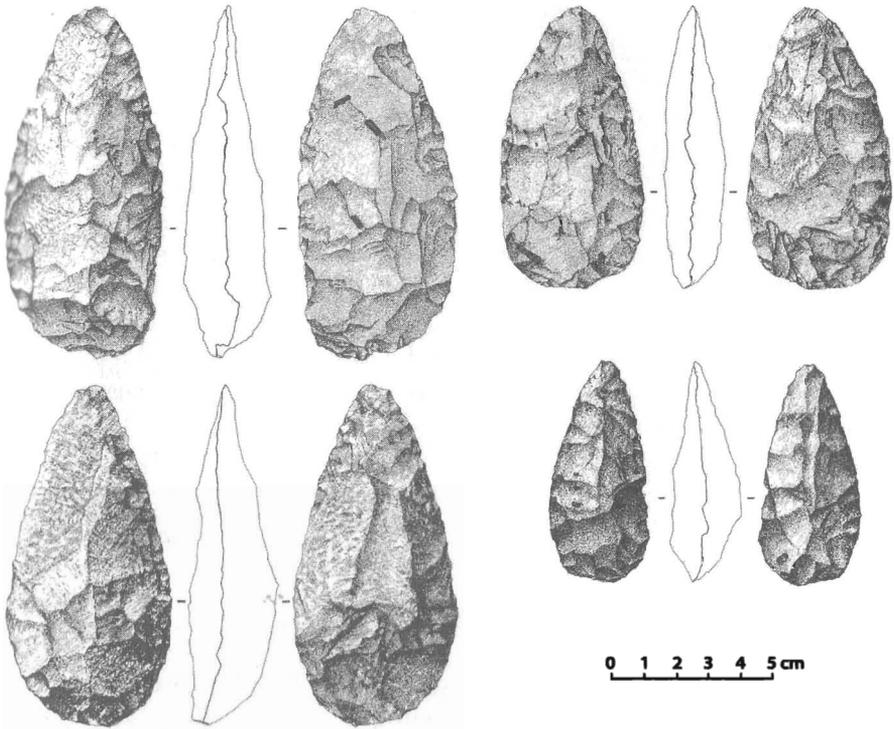


FIGURE 9.2. Bifaces from Isenya. (Figure is after Roche 2005; drawings are by M. Reduron, copyright Mission Préhistorique française au Kenya, director H. Roche, by permission of Hélène Roche.)

This standardized form of the Isenya bifaces is not strictly governed by production or use constraints; it is deliberate. Unless we can imagine that our ancestors moved around with a set of models, in the form of roughouts and preforms at different stages, this form must be associated with a specified mental image, meaning a concept of “their” biface (different forms exist in other geographic or chronological contexts). This means that the authors of these objects were capable of conceptualizing these tools, which thus constitute a true type.

To understand what this signifies, we can refer to a major distinction in psychology between percept and concept.

*A percept refers to the capacity to recognize something present to our senses. I see a pen, I touch a spoon, and I recognize these objects as a pen and a*

spoon. Animals are perfectly capable of percepts; a dog recognizes its leash and wags its tail at the prospect of taking a walk.

*A concept refers to the capacity to evoke a mental image in the absence of the object*, an image for which we can formulate commentaries and even imagine, mime, and describe its actions. Think of an orange, even though you do not have one visible to your eyes; you see it mentally, describe it, and even describe or mime how you would peel it according to your family tradition, and how your African neighbor would do the same, peeling it in a spiral.

It is extremely difficult to know if animals are capable of such operational conceptualizations. We know they are capable of perceptual recognitions and responses adapted to these percepts, but nothing indicates that they possess an operational mental imagery such as our own.

The production of shaped bifacial tools with a standardized shape attests to the capacity of their authors (probably *Homo erectus*, predecessors of Neanderthals, who themselves fabricated symmetrical bifaces) to conceptualize certain tools, which could be seen as a prerequisite to their denomination.

### **Levallois debitage: Planning by objectives, temporality of mental imagery, and propositional reasoning**

The Levallois debitage method (Levallois method of flaking) was discovered in Europe, on the banks of the Seine near Paris, and identified by Commont (1913) nearly a century ago. Although it may be older in Africa or Asia, it is considered to appear in Europe around 250,000 years ago at the beginning of the Middle Palaeolithic period, produced by Neanderthals. It consists of predetermining the general form of one or several flake products by a preliminary or subsequent (ensuing) preparation of the core (Boëda, Geneste, & Meignen 1990; Boëda 1994, 1995). Figure 9.3 shows a Levallois core and flake from Ault, a knapping site in northern France that yielded several hundred Levallois cores. On nearly 300 cores, the last flake scar removes an average of 70% of the flaking surface (Perpère 1999), proving that this last predetermined flake was intentional. The flake shown in the figure was probably abandoned because of its dull, hinged distal edge; it does not come from the core shown, but corresponds very closely. The position of the flake on the core reveals the faceted preparation of the striking platform. The upper face of the flake presents a large flake scar of

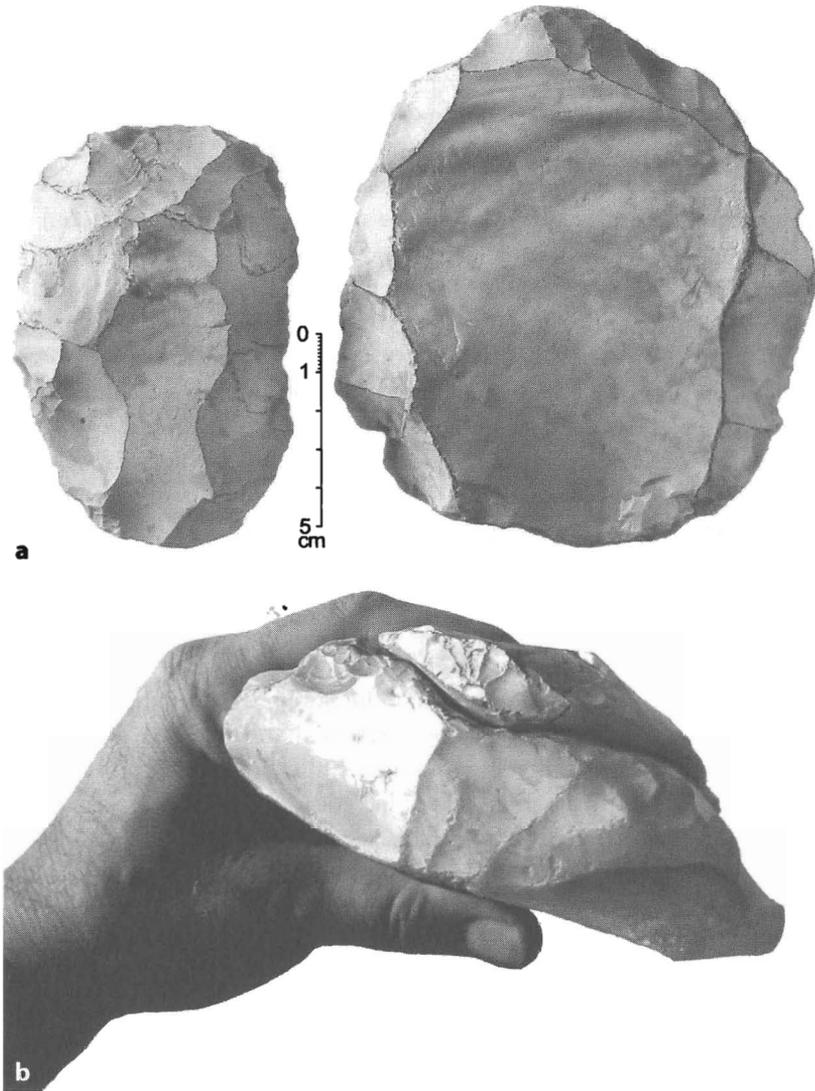


FIGURE 9.3. Levallois method of flaking: a, Levallois core (right) and flake (left) from Ault; b, the position of the flake on the core reveals the faceted preparation of the striking platform in a *chapeau de gendarme* shape, explained in figure 9.4. (Photograph by J. Pelegrin.)

a probable preceding Levallois flake in the same direction, after which the core was reprepared to allow the production of a second Levallois flake, shown in the figure.

Levallois debitage also includes several steps marked by changes in operation (“opening” of the roughout, initial shaping out, striking platform preparation, detachment of one or several flake products, reshaping out of the core, new preparation of one or more striking platforms, etc.) or technique (hammerstone change, use of an “abrader” to prepare the striking platform). They result in normalized, or even standardized, products independent of the initial morphology of the block. Figure 9.4 shows a diagram of the Levallois method with a preferential (intended) flake and *chapeau de gendarme* striking platform. Part a shows the preparation flakes on the debitage surface to create an adjusted convexity; part b indicates that preparation of the striking platform first consists of detaching two convergent flakes, separated just enough to create a small triangle in relief. Part c shows that a few fine bladelets are removed by a small, abrasive percussion to round off this triangle by faceting (if the bump thus formed is asymmetrical, too high, or too low relative to the plane of the debitage surface, the Levallois flake removed will be skewed, too thin, or too thick). Finally, part d shows that, if the strike is delivered with a correct oblique incidence, the hammerstone will attain the summit of the bump, determining the depth of the fracture plane, which will then cut through the prepared convexity of the debitage surface, all predetermining the thickness, width, and general form of the flake with a peripheral cutting edge.

Although the shaping of a rough biface can be interpreted as a progressive reduction, nonetheless requiring a strike-by-strike adjustment of the removals, Levallois debitage implies true planning according to objectives (giving a precise form to the debitage surface and to the platform, recreating an adequate convexity on the core, etc.), and not a chaining together of actions through a “recipe” or formula (detach a series of alternate or adjacent flakes, such as with the cores from Lokalalei 2C). In other words, the knapping procedure is guided by a series of specified forms to be obtained before passing to the next state, which must again be adapted to the preceding state. In this way, the technical modes (elementary actions) are clearly subordinated to the specified intentions or objectives, which correspond to knowledge.

An essential point is, therefore, that the details of the passage from one of these specified forms to another is highly variable: What counts is the

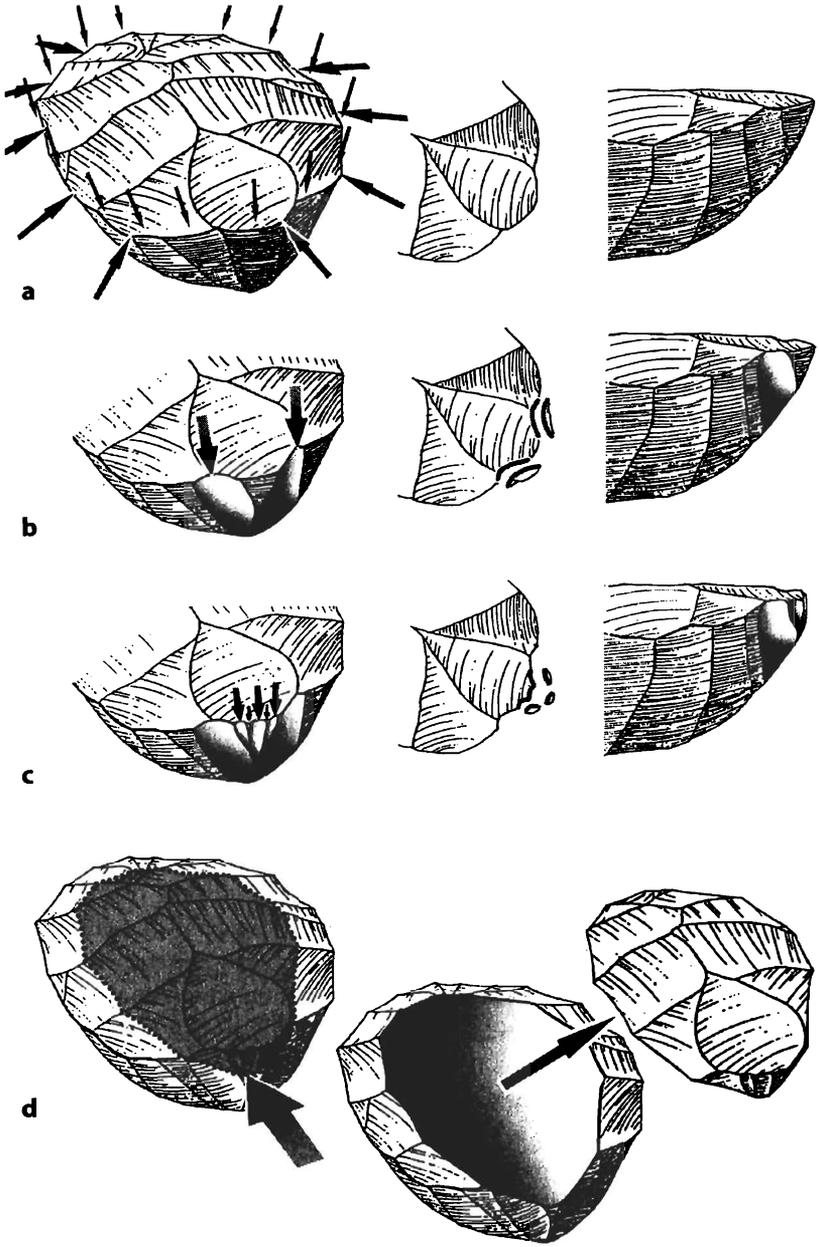


FIGURE 9.4. Diagram of the Levallois method with a preferential (intended) flake and *chapeau de gendarme* striking platform (after Pelegrin in Boëda and Pelegrin 1979–1980): a, surface preparation flakes to create an adjusted convexity; b, detachment of two convergent flakes, creating a small triangle in relief; c, removal of a few fine bladelets to round off this triangle by faceting; d, with correct delivery, the hammerstone will attain the summit of the bump. (Drawings by J. Pelegrin, DAO G. Monthel.)

result in terms of the form obtained, when the order and placement of these removals to maintain the debitage (flaking) surface are variable from one object to another, decided *ad hoc*. Based on a critical monitoring of the evolution of the piece, this flexibility shows the capacity to imagine solutions – how to organize the few flakes to follow, how to create a local striking platform to detach an important flake, and so on. These solutions are mentally evaluated as both possible (technically realizable) and desirable to advance toward the next intended state.

We have called this capacity “ideational know-how” in reference to ideational or constructive apraxia: motor disorders in which the combination of elementary actions is affected, whereas the capacity for individual actions is preserved.

Such reasoning thus activates a capacity to recall rules and anterior experiences in comparison to the present situation and to imagine what the piece can or will become following a given sequence of action. In these knapping productions, we are thus tempted to see the capacity to chronologically connote operational mental images; those that were memorized from experience, those present and evaluated, that of the ideal form that the object or part of it must obtain, and also those possible or virtual, requiring one operation or another in terms of the causes and consequences recalled and pondered.

This first illustrates the capacity of modern humans, us, to connote information, mental images, and events in time (capacity for temporality). This corresponds to our verbal “time” and the host of adverbs that allow us to recount what happened in the past and to distinguish what is happening now from what will happen next, using our past, present, and future tenses. We do all this without mixing the temporal connotations of these events or images, which could result in mental confusion or spatiotemporal disorientation.

This capacity for temporality is a powerful characteristic of language. Saying “I see a lion eating a gnu,” in the same way as an animal who signals an immediate situation, is of limited use because the person to whom you are talking can also see it, or turn his eyes to a simple signal. However, after a morning excursion, saying “I saw a lion that was eating a gnu behind the hill” is much more useful because this statement can initiate a collective decision, such as “at the hottest time of day, when the felines are sleeping, we will go to take the carcass.”

Second, we propose that the capacity to imagine what the piece will become following the imagined solution or action equals a form, or

beginning form, of propositional reasoning: “if I do this, the piece will become like this, if I do that, the piece will become like that.”

The capacity for propositional thinking, expressed by two propositions linked by *if* and *then*, apparently extends that of temporality: an initial event must first be connoted as anterior to that which follows. We consider it to be crucial in the technical sphere because it allows the emergence of conceptualized technogeometric rules (e.g., “it is the depth of the point of impact relative to the debitage surface that determines the thickness, and thus width, of the removal”). Being considered as conditional to the second, the first fact or event is seen as the cause of the second, which itself is seen as the consequence. Expected and verified by experience, this consequence becomes predictable, and even imaginable if the causal fact or event can itself be imagined, thus taking the value of reason. Reasoning can thus occur and be transmitted in the absence of the events in question in order to give supporting arguments for an intention and motivate collective decisions. In this case, it is the verbal form of the so-called conditional that is used: “if we watch the lions, [then] we will be able to take the carcass” and “if he had not left alone in the evening to drink, [then] he would not have been attacked.”

Whether or not it was fully conscious, the reasoning underlying Levallois technology by Neanderthals seems to have a propositional structure (Parker & Milbrath 1993) and is implicated in all knapping parameters. I refer here to the geometric parameters of knapping (for instance, the fact that given the convexity of the flaking surface of a core, the width of a flake is tied to its thickness), as well as to the dynamic parameters (effect of excessive or insufficient force and incidence; optimal relation between the mass and size of the expected flake and mass and hardness of the hammerstone, which also depends on the mass of the core).

Therefore, in my opinion, in terms of the cognitive capacities required for stone knapping, the essential points were already in place: the later realizations of *Homo sapiens*, in a given time or region, consist only of a diversification of performances permitted by the accumulation of innovations (new knapping techniques, new hafting methods, etc.).

### What can we conclude?

It would be tempting to imagine a first use of “names” as early as the Acheulean, and a fully constructed language, with diverse tenses and propositional expression, for Neanderthals and contemporary *Homo sapiens*, both

of whom employed the Levallois or equivalent debitage methods. But, I prefer to conclude more modestly: far from being a language specialist, I contribute here only a few technological observations and neuropsychological inferences that can participate in the debate concerning the origins of language. These inferences should be compared with those of other approaches, such as that of Coolidge and Wynn (2005), and then critiqued by linguists, neuropsychologists, and ethologists (Gibson & Ingold 1993).

In summary, I would like to make just one more remark concerning the chimpanzee Kanzi, who despite numerous knapping demonstrations and motivations (Toth et al. 1993; Schick, Toth, & Garufi 1999) never learned the basic principals of conchoidal fracture, which was already practiced by *Homo habilis* 2.6 million years ago (Roche 1980; Pelegrin 2005). A detailed examination of the “flakes” and actions produced by Kanzi indeed shows that his knapping skills extend no further than more or less violent and random hammering, which produces only splinters (detached by vertical blows, that is, by hardly controllable split fracture), and no true flakes by conchoidal fracture. In contrast with their excellent locomotor dexterity, the disappointing technical capacity of chimpanzees thus strongly indicates that the “technical” domain is much more an affair of conceptualization than one of motor dexterity, as language, also, is much more an affair of cognition than one of phonatory capacities.

## Language and the origin of symbolic thought

*Ian Tattersall*

To the best of our knowledge the possession of symbolic reasoning marks *Homo sapiens* as unique in the living world, both past and present. Until rather recently, though, our hominid precursors appear to have been non-symbolic, nonlinguistic creatures. That is to say, in certain very significant ways they more closely resembled other primates than they did modern human beings in the ways in which they perceived, and communicated information about, the world around them. This is not to say that earlier hominids were unsophisticated in their perceptive and communicative abilities, or even that they were necessarily *inferior* to us in those qualities. It is to say that they were *different*. Indeed, it is just this difference that may well in the end have made them lose out in the grand competition among hominids for ecological space and economic resources that took place in Africa, Europe, and Asia toward the close of the last Ice Age.

Prior to the dramatic spread of modern *Homo sapiens* at some time in the period centered at around 50,000 years ago, it had been routine for several different species of hominid to coexist in some manner throughout the Old World (see Figure 10.1; also see Tattersall 2000). However, in the few tens of millennia following the emergence of behaviorally modern *Homo sapiens*, all of our species' hominid competitors rapidly disappeared, in a process that certainly tells us more about the special nature of behaviorally modern *Homo sapiens* than it tells us about what it means to be a hominid in general. The abruptness and synchronicity of this Old-World-wide elimination of competing hominid forms suggests that, whatever it was about *Homo sapiens* that suddenly positioned our species as the sole hominid on the planet, it cannot simply have been an extrapolation of preexisting evolutionary trends in the human lineage: For a simple incremental addition to those trends, if

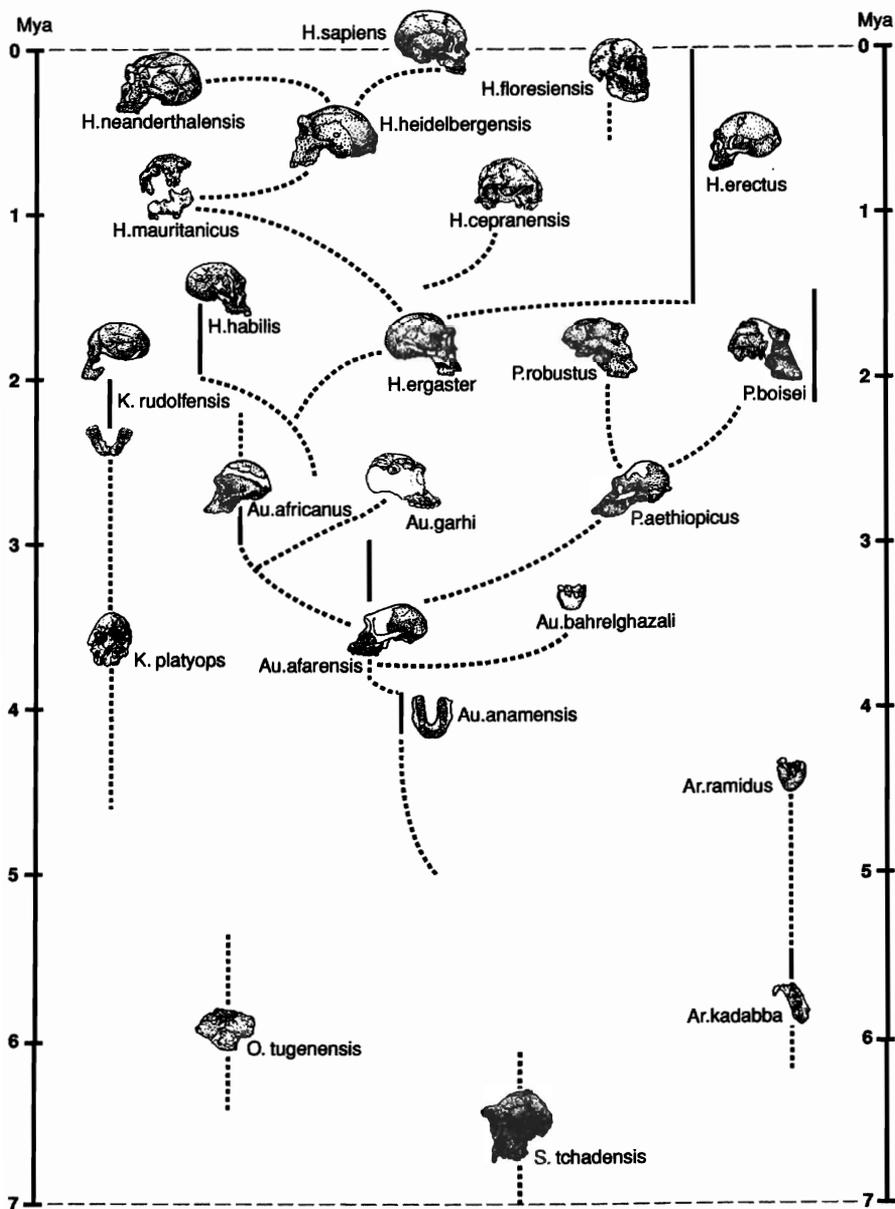


FIGURE 10.1. Highly provisional schema of hominid phylogeny, showing that species diversity has been a consistent theme throughout hominid history. Solid bars indicate known stratigraphic ranges; dotted lines indicate possible relationships.

indeed trends there were, is highly unlikely to have resulted in the wholesale elimination of all the competing lineages that had embodied them.

Clearly, with the arrival of our species, something truly new had appeared within the hominid family. In the next few paragraphs I shall look at the patterns of both biological and technological innovation that prevailed in hominid history prior to the emergence of *Homo sapiens*, in an attempt to understand the nature, or at least the context, of that event.<sup>1</sup> It is important to do this because the observed pattern in this history, which is one of highly sporadic change, contrasts dramatically with the linear thinking that has dominated palaeoanthropology since the 1950s, when the thinking behind the Evolutionary Synthesis (Dobzhansky 1944; Mayr 1950) came to dominate our science. With its emphasis on gradual generation by generation, within-lineage change, the Synthesis viewed hominid history as in essence that of a single lineage that was gradually burnished to its current perfection by the continuing pressure of natural selection. Even though new discoveries over the past several decades have obliged palaeoanthropologists to recognize that actual events were a lot more complex than this model admits, minimalist and progressivist interpretations of hominid history still tend to dominate our science, underpinned by a widespread perception that, for the past 2 million years at least, hominid history has largely been a story of not much more than increasing brain size and behavioral complexity.

The origins of the hominid family itself are still somewhat mysterious, but recent finds have clearly shown that the hominid family tree was bushy from the very start, some 7 million years ago (see Figure 10.1; also see Gibbons 2006). In other words, the early history of *Hominidae* was pretty conventional in the sense that its dominant signal is consistently one of evolutionary experimentation, of an ongoing exploration of the many ways that there evidently are to be hominid. The one feature allegedly shared by all of the very early fossil hominids is that all were terrestrial bipeds (Gibbons 2006), though in most cases this remains highly inferential. However, the early form of bipedality that these and the other “bipedal apes” of the period from about 6 to 2 million years ago exhibited is not well characterized as “transitional” between ancestral arboreality and modern

<sup>1</sup> I thank Sophie A. de Beaune for her kind invitation to participate in the Emergence of Cognitive Abilities colloquium held at the Congress of the International Union for Prehistoric and Protohistoric Sciences (IUPPS) in Lisbon, Portugal, on September 7, 2006.

striding terrestriality. This is because it was evidently a stable and successful adaptation that remained essentially unchanged for several million years, even as a variety of species belonging to this ancient hominid radiation came and went.

Throughout this period of adaptive stasis, it is hard to demonstrate that our ancient precursors had acquired cognitive capacities significantly in advance of those of today's apes. It is not until about 2.6 million years ago that the invention of crude stone tools announces what we can recognize as a significant cognitive advance (Schick & Toth 1993). Exactly which hominid made this fateful invention is unknown, but it is virtually certain that the hominid concerned possessed an archaic body build and a brain not much larger than one would expect in an ape of similar size (Tattersall 2004). This observation introduces a theme that we find repeated throughout hominid history: that biological and technological advances do *not* go hand in hand. This disconnect between anatomical and behavioral innovation actually makes eminent sense, for there is quite obviously no place that any innovation can arise, other than *within* a species. What is more, we see reflected here another pervasive theme: that hominid innovations, once established, have tended to persist for long periods of time – for a million years were to pass before any substantial change is observed in techniques of stone toolmaking.

The earliest stone tools were crude but effective, and the toolmakers were evidently simply after an *attribute*: a sharp cutting edge (Schick & Toth 1993). It apparently made little difference what the sharp flake actually looked like. Still, this innovation must have made an enormous difference in the economic lives of the early hominids, and it was a remarkably successful and durable one; techniques of stone toolmaking remained basically unchanged until about 1.6 million years ago, when an altogether new kind of tool was introduced: the so-called Acheulean handaxe, a larger implement consciously fashioned to a set and regular shape (see discussion by Klein 1999). Evidently, Acheulean toolmakers had started to shape stone according to a “mental template” that existed in their minds before toolmaking began, which is indirect evidence of another cognitive advance. Significantly, though, hominids of an altogether new kind had been around for several hundred thousand years *before* this innovation was made – for at a little under 2 million years ago, hominids of essentially modern body build had already appeared, best exemplified by the amazing 1.6-million-year-old Turkana Boy skeleton from northern Kenya (Walker & Leakey 1993).

These early upright striders, with brains perhaps a little bigger than those of the bipedal apes, but still little more than half the size of ours today, were the first hominids to be truly emancipated from the forest edge and woodland habitats to which their precursors had previously been confined. They rapidly spread far beyond Africa, the continent of their birth, as perhaps best documented at the extraordinary 1.8-million-year-old site of Dmanisi, in the Caucasus (e.g., Gabunia et al. 2000). They achieved this diaspora in the absence of stone tool-working technologies any more sophisticated, or brains significantly larger than, those of their predecessors. Only much later did the invention of the Acheulean announce the “discovery” of a new cognitive potential that had presumably lain unexploited since the novel anatomical form had appeared hundreds of thousands of years earlier.

Once more, there is a long wait for the next major technological innovation, which came in the form of core preparation whereby a stone core was carefully shaped until a single blow would detach a more-or-less finished tool. Again, this invention came long after a new kind of hominid had shown up in the fossil record, at about 600,000 years ago in Africa and shortly thereafter in Eurasia. It was hominids of this new species, *Homo heidelbergensis*, that by some 200,000 years later had introduced such important novelties as the building of shelters and the regular domestication of fire in hearths – though the first convincing evidence of domestic fire use comes a little earlier (Goren-Inbar et al. 2004). *Homo heidelbergensis* fossils also show flexed cranial bases and relatively short palates that may imply at least a nascent ability to produce the sounds associated today with speech – although it is important to note that there is nothing in the archaeological record of these creatures to suggest that they indulged in symbolic activities of any kind.

Perhaps the most accomplished practitioners of prepared-core toolmaking were the Neanderthals, *Homo neanderthalensis*. It is this species, which flourished in Europe and Western Asia following about 200,000 years ago, that provides us with the best mirror in which to see reflected the uniqueness of our own species, *Homo sapiens* – for although the Neanderthals had brains as large as ours, invented the burial of the dead, and clearly took care of disadvantaged members of society, they left little behind them to suggest that they possessed symbolic consciousness (e.g., Klein 1999). Furthermore, they were entirely evicted from their vast territory by arriving *Homo sapiens* whose existences were very clearly drenched in symbol (White 1986). Beginning some 40,000 years ago (and paralleled by similar processes that

apparently took place in Eastern Asia at about the same time), this eviction took not much more than a dozen millennia to complete. The early European *Homo sapiens*, familiarly known as the Cro Magnons, created astonishing art on the walls of caves. They carved exquisite figurines. They decorated everyday objects and made notations on plaques of bone. They played music on bone flutes, and without question sang and danced as well. In short, they were *us*. The material record they left behind is distinguished most notably from those of their non-African predecessors and contemporaries by its clear indications of a symbol-based mode of cognition.

But, significantly, the Cro Magnons were not the first creatures who *looked* just like us. The highly characteristic bony anatomy that distinguishes modern *Homo sapiens* may have had its roots in Africa as long as 160,000–200,000 years ago (White et al. 2003; McDougall et al. 2005), long before we find the earliest intimations of symbolic behaviors in that continent at about 100,000–80,000 years ago (Henshilwood et al. 2002). Similarly, although anatomically modern *Homo sapiens* shows up for the first time in the Levant at a little under 100,000 years ago, these early Levantine anatomical moderns were making stone toolkits virtually indistinguishable from those made by the Neanderthals with whom they apparently shared this region for upwards of 50,000 years, far longer than the period of cohabitation in Europe (Klein 1999).

Significantly, the final eviction of the Neanderthals from the Levant came right after the appearance there of stone tools equivalent to those the Cro Magnons brought with them into Europe. This suggests that cohabitation or alternation of some sort was possible as long as the behaviors of both *Homo neanderthalensis* and *Homo sapiens* could best be described as the most sophisticated extrapolations yet of the trends toward increasing brain size, and presumably of cognitive complexity, that had preceded them. However, once *Homo sapiens* began to behave in a “modern” way, we are faced with an entirely unanticipated phenomenon. With its advent the rules of the game changed entirely, and our species became an irresistible force in Nature, intolerant of competition and able to indulge that intolerance.

So what happened to allow the apparently radical reorganization of hominid cognition implied by this event? To answer this question it is necessary to recognize that, in evolution, form has to precede function, if only because without form there can be no function. Indeed, there is a strong argument to be made that any novelty must arise as an “exaptation,” an entity existing independently of any new function for which it might have

been suited and thus later co-opted. It may thus be permissible to speculate that the neural substrate for our remarkable symbolic cognitive abilities initially arose as a by-product of the extensive physical reorganization that we see so clearly reflected in our unique osteology. If so, the potential for symbolic cognition offered by this substrate must have lain unexploited for some considerable lapse of time until it was “discovered” by its possessors. This discovery must have been made, and its symbolic potential released, by some behavioral or cultural innovation.

The most plausible candidate for this cultural stimulus is the invention of language, an activity that is virtually synonymous with our symbolic reasoning ability – and that would certainly be impossible in its absence. Language involves forming intangible symbols in the mind, and it allows us to recombine those symbols in new ways, and to pose the “what if?” questions that permit us to be creative and to perceive and to relate to the world around us in an entirely unprecedented fashion. Of all characteristic human activities, the acquisition of language appears to be the most convincing behavioral releaser of our symbolic potential – especially because, unlike most other candidates such as theory of mind, it is a communal rather than an internalized attribute – and was thus an innovation that would have spread through the population with maximal rapidity. In this connection it is important to remember that by the time demonstrably symbolic behaviors had emerged the structures that permit speech were already in place, and had been for maybe as much as several hundred thousand years – having initially been acquired in some other context entirely.

Others are better qualified than I (see Wynn and Coolidge, this volume) to speculate about how and in what exact social context language was invented, by creatures that obviously *already* possessed the potential to acquire it. As an evolutionary biologist, though, I can point out that the exaptational process I have outlined needs no special explanation: that, indeed, it is thoroughly mundane in evolutionary terms. It is also clear that the acquisition of symbolic cognition was an *emergent* one, rather than a simple extrapolation of preexisting trends – for although our vaunted mental capacities are clearly based on earlier historical acquisitions, they were not *predicted* by them. Nevertheless, once the potential of these capacities was released, the way was open for this potential to be explored in all of its multifarious dimensions, in a process that is still continuing today.

All of this suggests that the modular view of the human capacity as an accretionary capability acquired in a series of sequential steps is misleading.

Patterns of the kind seen here does not suggest a process of gradual refinement under the benign hand of natural selection. Much as students of human structural and cognitive evolution have liked to think of our history as a more-or-less linear progression from primitiveness to perfection, this is clearly an inaccurate perspective. Above all, we should not be misled into unilineal thinking of this kind by the apparently consistent increase in hominid brain size over the past 2 million years. This undeniable average tendency is much more plausibly the product of the preferential survival of larger-brained hominid species than of generation-by-generation brain size increase – though the fate of the Neanderthals should serve to remind us that sheer brain size alone does not guarantee evolutionary success. It is also clear that, remarkable as our symbolic cognitive capacities are, they are not finely tuned for anything. Instead, they are an emergent expression. This means, of course, that we can neither blame the past for the unfortunate tendencies that our species exhibits today nor expect or even hope for evolution to perfect us in the future.

## Implications of a strict standard for recognizing modern cognition in prehistory

*Thomas Wynn and Frederick L. Coolidge*

Despite a decade of attention by archaeologists and cognitive scientists, considerable disagreement remains concerning the nature and timing of the evolution of modern cognition. Some scholars maintain that the modern mind emerged gradually over several hundred thousand years (McBrearty & Brooks 2000), whereas others argue for a rapid transition to modernity sometime between 100,000 years and 50,000 years (Klein & Edgar 2002). The range of proposed solutions is a result, we suggest, of an inconsistent set of standards for evaluation, derived largely from the inchoate nature of cognitive archaeology. In this chapter, we propose a strict standard for evaluation, and we apply this standard to the known archaeological record. The result places modern cognition very late on the stage of human evolution.

Informal approaches to an archaeology of cognition have provided inconsistent results. Two such approaches have caused the most confusion: traditional technocultural taxonomies and trait lists. The technocultural taxonomies still in use today in archaeological discourse were defined over a century ago for Europe, and eight decades ago for Africa. They are organizational systems that were arbitrarily defined on the basis of tool types and manufacturing techniques. They enabled Palaeolithic specialists to impose order on their collections, and they also provided a sequence chronology in the era preceding chronometric dating. These taxonomies also carried controversial implications about human groups and cultural affiliations that remain unresolved. None of the units was defined with cognition in mind, and it is inappropriate to use any of them as proxies for modern cognition. All Palaeolithic specialists know this, but the taxonomies continue

to wield an uncanny effect. We still tend to think in terms of the Aurignacian as a unit vs. the Mousterian as a unit, as if they were real, coherent entities binding together a myriad of modern or premodern characteristics. As a direct response to the vagueness of traditional technocultural units, many archaeologists have turned to lists of explicit traits whose presence in archaeological sites can act as litmus tests for modernity. The most influential of these has been that of Mellars (1996). Such lists have the advantage of eschewing the troubling baggage of the traditional technocultural units. They are also more open to critique, as when McBrearty and Brooks (2000) used a Eurocentric list to argue for gradual evolution in Africa. Such lists could be very effective, but only if serious scholars agreed that the traits marked modern culture, or modern behavior, or modern minds. Herein lies the problem. Heretofore, such trait lists have been compiled from archaeological evidence: those traits associated with prehistoric people who are presumed to have been modern (e.g., European Upper Palaeolithic) can be used to stand for modern behavior. The circularity is obvious and problematic (which does not mean the lists are necessarily wrong). The problem with lists is also appreciated by most archaeologists, and it has been explicitly discussed at length by Henshilwood and Marean (2003). The real weakness of such lists is that they approach the problem of modernity the wrong way around. Instead of starting with archaeological remains, we need to start with the behavior in question and generate archaeological visible sequelae.

### **Cognitive archaeology and the strict standard**

To be persuasive, a cognitive archaeological argument must meet **three** methodological requirements. First, it is necessary that the archaeologist understand the cognitive ability in question. If one wants to argue about modern cognition, one must first know what features of human cognition are, in fact, modern. This requires some background in cognitive science; commonsense understandings are not sufficient. Second, the archaeologist must identify specific actions or sets of actions that are enabled by the ability in question. The archaeological record consists of traces of action, not direct traces of minds, and the link between action and cognition must be explicit. Finally, the archaeologist must then define a set of criteria (attributes) by which these actions can be reliably identified in the archaeological record.

If one structures an argument in cognitive archaeology appropriately, it is then possible to apply different standards of evaluation to the evidence. The strict standard, which is the only one with real persuasive power, has the following two components.

1. Cognitive validity: The evidence must actually require the abilities attributed to it. The cognitive ability must be one recognized or defined by cognitive science; it must be required for the actions cited; and the archaeological traces must require those actions. A strict standard of parsimony must apply. If the archaeological traces could have been generated by simpler actions, or simpler cognition, then the simpler explanation must be favored.
2. Archaeological validity: The archaeological evidence must itself be credible. The traces in question must be reliably identified and placed appropriately in time and space.

This strict standard is no different from any serious archaeological argument, but it is remarkable how rarely it has been applied. The case of Palaeolithic beads is a telling example. Many archaeologists (Ambrose 1998; McBrearty & Brooks 2000; d'Errico et al. 2001; Henshilwood & Marean 2003) have used them as a marker of modern cognition. Most of the attention has been given to the archaeological credibility of various examples. d'Errico et al. (2001), for example, has made a careful and convincing case for the presence of beads at Blombos Cave, easily fulfilling the second requirement of the strict standard. However, for the argument to meet the strict standard, it must also make a convincing case that beads required the actions posited (in this case, symbolism), and that the posited action required modern cognition. This argument must be explicit. To date, this link in the argument for beads has been weak at best. No one has supplied a persuasive, cognitively based justification for considering symbolism to require modern cognition, or for beads to require symbolism (but see Henshilwood and Dubreuil in press). It is little more than an assertion about which archaeologists seem to agree. It is important to be clear about the sense in which the bead argument fails: it fails as a *cognitive* argument. Archaeologists can still use beads as a marker of a modern way of life, or modern culture, or society (assuming that they have good theoretical support for these formulations). However, to be a cognitive argument it must have a cognitive grounding, and it doesn't, at least not yet.

In previous papers (Coolidge et al. 2001; Coolidge & Wynn 2001, 2005; Wynn & Coolidge 2003, 2004) we have argued that an enhancement in working-memory capacity enabled modern executive functions, which are the basis of modern planning abilities. The cognitive basis of this argument puts us in a position to apply the strict standard.

### **Enhanced working memory and executive functions of the frontal lobe**

The argument is based on Baddeley and Hitch's (1974) original concept of working memory. As conceived of by Baddeley and Hitch, and recently modified by Baddeley and Logie (1999) and Baddeley (2001), working memory is a tripartite cognitive system consisting of a central executive, primarily involved in maintaining relevant attention and decision making, and two slave systems, phonological storage or articulatory loop for the maintenance of speech-based information and the visuospatial sketchpad, an interface for visual and spatial information. At the level of measurable behavior, the attention and decision-making components of the central executive are most clearly evident in the executive functions of the frontal lobes, which include our modern abilities to plan ahead and strategize. We have offered evidence from behavioral genetics for the highly heritable basis of the executive functions of working memory and its slave systems and hypothesized that a relatively simple mutation in this system may have produced fully modern thinking. We further postulated that this mutation was either specific to phonological storage, and resulted in a lengthened capacity to maintain speech sounds, or was more generic and resulted in an enhancement of the general capacity of the central executive. The latter might have included a greater ability to maintain attention despite competing but nonrelevant stimuli. Because working memory has been empirically shown to be strongly related to both general intelligence (Kyllonen 1996) and native, fluid intelligence (Kane & Engle 2002), this mutation might have subsequently had a profound positive effect on the general reasoning abilities of modern humans. We have labeled this effect "enhanced working memory." We have also reviewed archaeological evidence that supports a relatively recent date for such a mutation. Even if it yielded only a slight selective advantage, such a mutation could have spread rapidly in African populations, enabling the dramatic spread of anatomically and behaviorally modern humans after 50,000 years.

## Defining attributes and applying the strict standard

Having established the validity and importance of enhanced working memory in modern cognition, the next step is to identify behavioral sequelae that might be visible in the archaeological record. Here we must turn to the executive functions of the frontal lobes themselves, which are the clearest behavioral manifestations of enhanced working memory. Executive functions include such abilities as resistance to interference, inhibition of prepotent responses, organizing across space and time, contingency planning, mental rehearsal, and thought experiment (Barkley 2001; Coolidge & Wynn 2005). The methodological hurdle is to identify archaeological patterns that were generated by executive functions but that *could not have been produced by simpler cognitive strategies*. A simple measure of technical or other complexity will not do; procedural memory can generate complex technical sequences without recourse to executive functions (Ericsson & Delaney 1999). Indeed, such expert performances had been the foundation for much of hominid culture for over 1 million years (Wynn & Coolidge 2004). It is necessary to look beyond the standard typologies and technological units. In the paragraphs that follow, we list a number of activities that would require executive functions and are potentially visible in the archaeological record. After each, we apply the strict standard of evaluation to identify the earliest evidence for that activity in the archaeological record.

## Technology

Even in the modern world, most technical products fall in the province of expertise and procedural cognition. Yes, many modern artifacts were initially the result of conscious invention using executive functions and enhanced working memory, but unless we can see the process of invention, it is almost impossible to eliminate a scenario in which technical changes accrued over generations and thus were not the result of active creativity. This is especially true of the palaeotechnic systems of the Stone Age. But technology is not entirely mute. Certain neotechnic procedures require the kinds of long-range temporal and spatial planning typical of executive functions. Alloying metals and kiln-fired ceramics are two examples; however, these appeared so recently in the prehistoric record that they cast no light on the evolutionary question. The standard lithic markers of

modernity – blades – are no help at all; they are easily within the range of an expert technical system and did not require any leap in cognition.

Tools themselves, especially stone tools, supply no “smoking guns” for modern cognition, but strategies of tool use do. We find that Peter Bleed’s (1986) distinction between maintainable and reliable technologies has definite implications for executive functions. Maintainable tools are easily made and easily repaired, and they characterized human technology for the first 2 million years of prehistory. Reliable tools are designed to reduce possibility of failure. The artisan invested labor up front to ensure the successful deployment of the tool when necessary. This is a kind of contingency planning. Note that it is not the making of the tool that implies executive functions, but rather the long-range strategy of the system. Reliable technologies fulfill the first criterion of the strict standard, which is cognitive validity. Valid archaeological evidence for reliable technologies yields the following results.

1. Facilities: The most convincing prehistoric examples are facilities (Oswalt 1976) – traps, fish weirs, and so on. They require heavy investment in labor, and they often work remotely in time and space. They characterize Mesolithic, Epipalaeolithic, and Archaic technologies around the world, but are virtually unknown earlier.
2. Bone and antler armatures: These have often been cited as evidence for modern cognition. Their appropriateness as evidence for executive functions hinges on whether or not they were true reliable technologies. Given the number of hours required to make an atlatl propelled barbed harpoon set, we are comfortable extending reliable technologies back to the Late Upper Palaeolithic in Europe. The simpler sagaies of the Early Upper Palaeolithic are less convincing, as are the bone points of the African Middle Stone Age. They were not clearly elements of a reliable system and so cannot be used to argue for executive functions.

### **Foraging systems**

The reconstruction of prehistoric foraging systems is inherently less reliable than the descriptions of technology because it relies on longer chains of inference. Nevertheless, archaeology has made a concerted assault on prehistoric foraging for over half a century, and this persistence has yielded

an account of the evolution of foraging that is complete enough for the task at hand.

The key step in a cognitive evaluation of foraging is the identification of appropriate attributes of foraging systems that require modern executive functions. In examining the literature on modern foraging, we found two executive functions to be ubiquitous: long-range temporal and spatial planning, and large-scale response inhibition. These are clearly required for agricultural systems, but they are also evident in the scheduling practices of modern foragers – cycles of landscape burning in Western Australia are one example, and the historic movement of plants to new habitats by Southern Californians another. Modern humans manipulate their food supply and plan ahead on a seasonal and multiyear basis. Elsewhere (Wynn & Coolidge 2003) we have termed this “managed foraging,” which is an umbrella term encompassing all modern agricultural, fishing, collecting, and foraging subsistence. Managed foraging meets the first criterion of the strict standard, cognitive validity.

The strict standard requires unequivocal archaeological evidence for managed foraging. Archaeological traces of food production extend evidence for managed foraging back to the Pleistocene–Holocene boundary in some regions of the world, and soon thereafter in others. Epipalaeolithic systems of broad spectrum foraging extend the record back several thousand more years. The record in the Levant is especially persuasive; residents at Abu Hureyra (Moore, Hillman, & Legge 2000) exploited a wide range of plant and animal foods, but what is more telling was their response to the advent of the Younger Dryas climatic deterioration when they adjusted their foraging to changing conditions, including the manipulation of wild cereals.

Evidence for managed foraging prior to the Epipalaeolithic is more problematic. There is persuasive evidence for storage of meat just prior to the last glacial maximum on the Russian plain (Soffer 1989), and storage is a good indicator of response inhibition, at least. On the Iberian peninsula, Magdalenian foraging was “a very specialized system (begun at least during the Last Glacial Maximum) that included the interception and massive slaughter of migrating *Rangifer* herds; as well as more individualized killing on summer and winter pastures” (Straus 1996:90). Recall that these Magdalenian hunters also produced a reliable technology. Later Stone Age foragers in South Africa, dating to about 23,000 years ago, exploited corms and may well have used fire and landscape modification to do so,

a clear indication of managed foraging (Deacon 1993). Recently, Barker et al. (2007) have made a provocative case for the use of fire and traps at Niah Cave, Borneo, predating 28,000 years ago.

Evidence from earlier than Niah Cave is more equivocal. Specialized hunting does not itself require management or executive functions. Indeed, the kinds of specialized hunting evident in the Early Upper Palaeolithic was little different from that practiced by Neanderthals in the Middle Palaeolithic (Grayson & Delpech 2002). Although there were differences in detail, and probably in tactics, nothing in the foraging of Early Upper Palaeolithic or the early Late Stone Age people meets the strict standard.

### Algorithmic devices

Technology and subsistence are the action domains that are most accessible to the archaeologists. With decent preservation and good recovery techniques we can count on being able to identify something about each. When we apply the strict standard of evaluation, they both tell the same story: Modern executive functions and working memory were in place by perhaps 30,000 years ago, but evidence for earlier acquisition is weak. Of course, technology and subsistence are mundane domains of action, and even in the modern world rarely tap into our most sophisticated thinking. Perhaps the domain of symbolic thought, long the standard bearer for cognitive archaeology, will yield an older signature.

There is no doubting that modern culture is symbolic culture, and that an understanding of the evolution of human cognition requires an understanding of symbol use. But symbol use is not synonymous with modern cognition; it is one component of modern cognition. Documenting the presence of symbols does not also document modern cognition. Barham (2007) has recently suggested decoupling symbolism from discussions of the modern mind, and we heartily concur. Our task at hand is documenting the use of executive functions and enhanced working memory, and symbolism is not a proxy. In theory, symbolic artifacts could exist in the absence of executive functions; there is nothing about arbitrary reference that requires the attention capacity of enhanced working memory. Nevertheless, some of the artifacts invoked in the discussion of symbolism do have implications for executive functions. These are the algorithmic devices.

An algorithmic device is an artifact, such as an abacus or a calendar, whose job is to assist human calculations. Their role in cognition is to

expand the capacity of working memory, freeing it from the necessity of holding information in active attention, and thereby freeing up capacity for the performance of more complex calculations. They are also compelling evidence for an expanded working-memory capacity itself because the manipulation of the device requires working-memory capacity independent of any specific problem. d'Errico (2001) and Marshack (1991) have published extensively on one variety of such devices, the notched and engraved bones and plaques of the Late Palaeolithic. To meet the strict criterion, it is necessary that the notched plaques truly have been calculating devices. The notches need to have been made at different times, attesting to their role as external memory algorithms. The Tai plaque is a convincing example that dates to the Iberian Final Magdalenian. There are earlier examples of notching in the European Upper Palaeolithic (Aurignacian) such as the Blanchard plaque (Marshack 1985), but here the notches are not clearly sequential and so fail to meet the strict standard. The cross-hatching on the Blombos bones and ochre are not sequential marks, and no claim can be made for an algorithmic function. Here again, the strict standard identifies executive functions in the European Late Upper Palaeolithic, but not earlier.

The Palaeolithic record boasts occasional provocative artifacts that challenge our interpretive abilities. The Hohlenstein-Stadel figurine is one such object (see Figure 11.1). This well-known lion-headed human image (or human-bodied lion) strikes all of us as familiar and modern, but did it require modern executive functions? Somewhere in his or her mind, the artisan combined the features of one entity with those from a very different content domain. This is analogical reasoning, and is a *sine qua non* of modern executive functions. If the Hohlenstein-Stadel figurine is reliably dated to 32,000–34,000 years, it is the earliest artifact that meets the strict standard of evaluation for modern executive functions.

## Conclusion and discussion

When we apply the strict standard, an unsettling result emerges. Technology, subsistence, and algorithmic devices all point to a late emergence of modern executive functions. Most of the evidence postdates 30,000 years, and it is not until 15,000 years or so that executive functions appear to have been ubiquitous.

Scholars can interpret this result in four rather different ways.

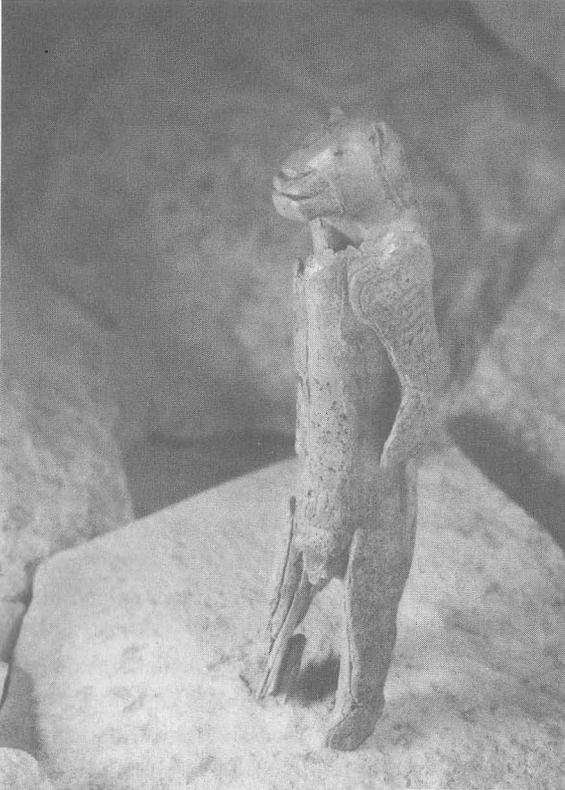


FIGURE 11.1. Hohlenstein-Stadel figurine, 29.6 cm, from the Aurignacian period. (Courtesy of the Ulmer Museum.)

1. Reject it entirely: Absence of evidence is not evidence of absence, or so the adage goes. The taphonomic threshold (Bednarik 1994) and the serendipity of archaeological discovery have yielded a misleading signature. Moreover, the strict standard is too strict, and it places unreasonable demands on archaeological inference.
2. This is the expected signature of the ratchet effect of culture change. Executive functions evolved long before 30,000 years ago and enabled modern innovation and culture change, but millennia were required before these changes accumulated to the point of archaeological visibility.

- 1 The mutation enabling enhanced working memory occurred long before 30,000 years ago, but required millennia to increase in frequency to levels at which significant numbers of people expressed the executive functions that are necessary for group planning (note that this interpretation is similar to Option 2, but here the emphasis is on biological process, not culture change).
- 4 The signature is accurate. Enhanced working memory and executive functions evolved late in a human population that was already anatomically modern. They then spread very rapidly because of their clear advantage in long-term planning and innovative responses to challenge.

A salient and long-known feature of the Palaeolithic record would appear to favor Option 4: After 20,000 years, the pace of culture change accelerated very rapidly. Yes, there were significant climatic events associated with Late Pleistocene environments, but there had been significant environmental changes many times before without such a dramatic response. This time, the human response to Late Pleistocene challenges was facilitated by modern executive functions, and the long-term consequence was, ultimately, the modern world.

## Imagination and recursion: Issues in the emergence of language

*Eric Reuland*

Prima facie, the complexity of human language is daunting. Nothing short of a miracle may seem to have been needed for its emergence, turning a nonhuman ancestor into one of us. Given the obvious time limitations on the data, an investigation of the emergence of language may appear to be riddled with speculation. However, fields as different as evolutionary biology and cosmology as a branch of astronomy struggle with similar limitations. They show that a systematic decomposition of complex patterns allows us to keep speculation within bounds, and create models that do enhance our understanding of “how it started.” A realistic evolutionary perspective on language, then, may also come within reach once a proper decomposition has been obtained. Contributing to this end is the goal of this chapter.

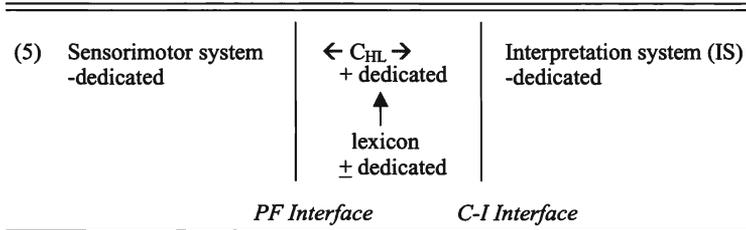
### Preparing the enterprise

For a proper start of the enterprise, it is of the utmost importance to distinguish between the following issues.

1. The first is the evolution of “man” up to the emergence of the language faculty.
2. The second is the emergence of the language faculty.
3. The third is the emergence of language.
4. The fourth is the subsequent evolution of mankind and her language.

Each of these points (1–4) reflects different questions and hence requires different windows in the sense of Botha (2006). Let us first place these questions in perspective, using Chomsky’s (1998, 6) evolutionary fable as a

TABLE 12.1. *A schematic representation of the minimal language system (Chomsky 1995)*



starting point: Given a primate with the human mental architecture and sensorimotor (SM) apparatus in place, but not yet a language organ, what specifications does some language organ have to meet if, upon insertion, it is to work properly?

Language minimally involves the availability of a computational system that effects a mapping between forms (sound, gestures) and meaning (in the form of internal representations of the world, or thought). In line with Chomsky (1995), I will let  $C_{HL}$  stand for the computational system of human language.  $C_{HL}$  is, then, a combinatorial system over lexical elements, in which each element represents an elementary sound–meaning pairing.<sup>1</sup> Using the terms PF (or phonetic form) interface (Phonetic Form) and C-I (or conceptual-intentional) interface (Conceptual-Intentional) for the interfaces with the sound system and the interpretation systems, respectively, we get the following schema that as such should not evoke too much controversy (See Table 12.1).

The PF interface must provide a procedure for mapping the complex structures provided by the  $C_{HL}$  onto instructions for the representation system. The C-I interface must provide a compositional procedure for the interpretation of the whole on the basis of the interpretation of the component parts and the way in which they interact.

Our capacity for language obviously relies on many processes that are not dedicated to language. Our articulatory system is used for functions varying from eating to respiration. Our auditory system can process sounds from falling rock to bird song; our thought system can process smells and calculate distances between predators and safe havens. It can estimate the speed required to get to the latter on time, and so on.

<sup>1</sup> The basic units need not coincide with our pretheoretical conception of words. Some units are certainly smaller. Some may also be larger, as certain researchers hold.

Our lexicon is closely related to our conceptual system, the system that allows us to organize our internal representation of the world around us. The concepts of elephant, sloth, trout, poison ivy, fear, running, and hunting are independently important to have for any being that is trying to get around in our world. Having them is really not even specific to man. Hence, they are not dedicated to language. Therefore, insofar as a concept is part of the lexical entry *sloth*, *running*, and so on, which represents the mapping between these concepts and the arbitrary sound sequence indicated by the italics, such an entry cannot be completely dedicated either.<sup>2</sup>

Given this schema, we must determine what properties  $C_{HL}$  must minimally have to do its job and, what is equally important, what properties the thought systems must have for having  $C_{HL}$  to be any good (Chomsky 1998).<sup>3</sup>

### Preconditions

Crucial for the preconditions of language are these: What set things in motion leading to Phase 1, preparing the scene for  $C_{HL}$  to be inserted? In addition, already on the verge of Phase 2, what is it we minimally must assume to have been inserted?

<sup>2</sup> See Reinhart (2002) and Reinhart and Siloni (2005) for an account of what properties of a concept are readable to  $C_{HL}$ . Note that there are many lexical items whose semantic properties cannot be readily understood in conceptual terms. Some of these are, for instance, articles such as *the*, prepositions such as *of* in *the destruction of education*, and elements such as *such* and *as*, etc. These reflect the *functional* structure of the sentence. It is very important to realize that their existence and the important role they play in the language put severe limits on a too naïve conception of language as a symbolic system.

<sup>3</sup> This phrasing requires an important caveat. From our primordial soup, there developed beings that are as different as squids, *Escherichia coli*, Jacaranda trees, sloths, and us. This relativizes any story about adaptive values. As Boncinelli (2005) points out, “adaptive value” is not a straightforward notion. A trait may give an adaptive advantage in one habitat, but not in another. It is, therefore, always relative to a “niche.” Such a niche can be reflected in a particular environment (forest, plains, desert, swamp), but also in what I will term an *evolutionary path*. That is, even if the original environmental conditions defining a particular niche are no longer there, the further evolutionary development may have acquired its own dynamics. This can be understood in terms of a so-called natural logic, as discussed in Oller (2007). For instance, the evolutionary path of “predator” carries an internal dynamic that is quite different from the path “big herbivore,” and it would be virtually impossible to cross over from one path to the other. Similarly, once a species started investing in brain power, it will be quite difficult to skip this and move to something else. Of course, what may happen is a split in the path. A population may split at some point and the resulting groups may develop in different directions.

Clearly, the development of motor systems and vocal tract must have taken place under the influence of factors other than language. The same holds for cognitive development. High-level cognitive skills can be independently useful. If you are living in trees and ended up in the evolutionary path of “tree dweller moving around quickly” (that is, you are certainly not in the sloth niche, but why you did not end up there is a different matter), it may contribute to your chances of survival if you are able to compute the optimal path from one branch or tree to another. So, if the competition you are engaged in is that of moving around in a complex three-dimensional world, trying to get a grip on it during your movements with tail, feet, and hands, this puts heavy demands on the computational capacity dedicated to instructing the motor system. Crucially, as a natural next step, it also makes it useful to compute and evaluate alternative routes. But that is an even more demanding task. That is, it involves constructing, rotating (around three axes), and modifying three-dimensional models of a complex world and matching them with reality. The ability to compute alternatives comes with a straightforward bonus. If you are computing alternative paths, trying to avoid a branch, it is a relatively small step to start computing a path in a world similar to the actual world in which there is no branch, and to adapt the world to your model by removing the branch. Then, if you want to grasp a piece of fruit hanging above you, and you cannot reach it, you can either climb a stretch, or else envisage a world in which your arm is long enough, and make it so, by grabbing a loose branch, or if there are no loose branches by loosening one.

In this story, we made a couple of very small steps, the result of each easily seen within the scope of the previous stage. Nevertheless, the end result is impressive, as we can more readily see if we give it its proper qualification: *imagination*. The comparison of alternative paths toward a goal, optimization, and adapting the environment to what is needed to realize that goal: In the end, all depend on being able to handle nonexisting – *imagined* – rather than existing states of affairs. Let’s take the ability to manipulate and compare models of the world that differ from the internalized world model as it presents itself to the senses as the hallmark of imagination. If so, it is still nontrivial to determine whether a particular creature has the gift of imagination.

Surely, not every type of goal-directed behavior should qualify as imagination. A cat’s seeing a mouse may start a series of actions that one could say are directed toward catching it – rarely with any success in the case

of my cats, though – but one better not ascribe to one's cat any form of imagination. A chimp putting together a tool to get to a banana should in some sense qualify, though.

One can see that once imagination is in place the ghost easily gets out of the bottle. If you are facing an opponent you may wonder what he is going to do. Imagination may suggest to you: What if I were him? This may be quite useful provided that you and he are not too unlike. So, what will not help with a snake may well be quite helpful with a human. Give our ancestor sufficient imagination, and human theory of mind is born.

But, of course, the operative term is *sufficient*. Whatever impressive feats our chimps are able to perform, they are not a shadow of what we are able to. So, even in imagination, there are differences to observe. The question, then, is this: Are these differences just quantitative, or is there a qualitative aspect to it? Clearly, quantitative issues do arise. Logically, some creature could have the possibility to construct a model of the world that differs from the internalized world model as it presents itself to the senses, without having the possibility to compare these, as a result of limited processing resources. Thus, sufficient working memory – to put a simple name on a complex system – is a condition for imagination being any use at all. But is that all?

Bischof-Koehler (2006) discusses an interesting limitation on theory of mind. As already indicated herein, theory of mind can be seen as the ability to view a situation from the perspective of another participant in that situation; that is, imagining oneself to be in the other's shoes. In the research that this author reports on, chimps and young children can judge a situation from the perspective of another participant. So, they have the imagination needed for having some sort of theory of mind. However, what they cannot do is put into the equation the perspective the other participant has on their perspective on him. To be able to do this, one must minimally be a 4-year-old human. This brings the issue of having a proper theory of mind close to another issue that figured prominently in the discussion of the evolution of language since the seminal 2002 article by Hauser et al., namely *recursion*: This is what incorporating into your perspective on the situation the perspective the other participant has on your perspective on him amounts to.

In terms of model building, this means that, while carrying out the instruction *Build Model* – to build your world model (of the world around you or some variant of it) – you can call the instruction *Build Model* to

build a model within your model, and so on. And what this leads to is not only a theory of mind, but planning – planning to change the world to meet your needs, planning to manipulate others to serve your goals. This is planning of a type that puts a huge demand on processing resources. This is planning of a type that, once in place, puts a considerable bonus on efficient encoding and efficient storing of your models while you are working with them.

However, to be eligible for the bonus, some planning facility must already be in place, together with the processing resources minimally needed. The question is, then, where such processing resources may have come from. A simple answer may be that they come from having to cope with changing circumstances, from benign to adverse, and vice versa. An organism that is challenged to the limits of its capacities by adverse conditions may free these resources for other applications if the conditions change to benign. Again, little follows as yet. For instance, adverse climatic conditions may be met by amassing huge amounts of fat, isolating fur, and so on. However, if you are already on an evolutionary path that meets its challenges by modeling alternatives – irrespective of what caused you to start on this path – a cycle of climatic changes may provide a boost. For instance, if at some point you have to leave your life in the trees because of changes in the environment, what will happen? It is quite natural that all this great computational power needed for your life in the three-dimensional world of the trees gets applied to the far simpler task of navigating in the two-dimensional environment of the plains, and the excess power becomes available for new areas of application, which if successful keep refueling the direction of change.

Oppenheimer (2004) tells an intriguing story of human evolution during the past 2.5 million years and the effects of change in the form of repeated glacial cycles. As he notes, by 1 million years ago, brain volumes of hominid species had increased from 400 cc to 1,000 cc. Although one must be careful not to postulate a too simplistic connection between brain size and brain quality, given the circumstances it does not seem unreasonable to assume that this increase was due to competitive selection on an evolutionary path where investing in processing resources paid off. Oppenheimer notes another interesting fact. Increase was the sharpest in the earlier period. The curve starts flattening after roughly 1 million years, and an overall decline – although not overly dramatic – in brain volume started with the emergence of modern man, an event that Oppenheimer puts around 170,000 years

ago. The question is, then, why a decline of brain volume set in. Are there diminishing returns, along the lines discussed by Oppenheimer? Possibly, but there is an alternative, namely that the emergence of modern man is defined by a qualitative change in the nature of the computations the brain was able to carry out. This would be a change allowing the same gross computational capacity to be applied in a way that, being better, obviated the need for more.

### *Matching events of different types*

One of the challenges one faces is how to match what is known about the developmental process with possible dramatic changes in potential of the actors. For instance, if modern man emerged around 170,000 years ago, it is striking that the first successful exodus of modern man from Africa took place only around 85,000 years ago – with an unsuccessful attempt some 10,000 years earlier (see Oppenheimer 2004 for discussion). Given the sequence of dramatic climatic changes in the period before, climate and environmental resources cannot be the explanation. Conditions of a low enough sea level were also occasionally satisfied during that period. Given the nature of the challenge an exodus posed, it seems more reasonable to hypothesize that the task only became possible because only then man became up to it. That is, man became able to successfully set up, weigh, choose, and maintain alternative world models as long-term goals and systematically work toward their realization. So, can we expect a substantive qualitative leap around 85,000 years?

There is extensive discussion in the literature about a symbolic explosion at a much later date, which could reflect a qualitative leap. As Noble and Davidson (1996) claim, there is a considerable time lag between the emergence of *Homo sapiens* (anatomically modern human forms) – which they put at 100,000 years – and indications of behavior typical of the modern species. Lock (2004) notes that, during a long initial period, there is little substantive change in the archaeological record associated with modern human forms. Much like earlier human ancestors, they produce tools; one finds traces of coloring on artifacts; there is evidence of shells with artificial holes; and so on. But for tens of thousands of years, there is nothing in the form of fundamental changes. According to Lock there is no evidence of symbolic behavior before the Upper Palaeolithic (30,000 years ago). It is

only from around this time that conclusively positive evidence is reported, such as the discovery of figurines such as the lion man from Stadel,<sup>4</sup> crucially depicting an impossible object. Thus, according to authors such as Lock, something like a symbolic explosion appears to have occurred somewhere around 30,000 years ago.

What does this tell us? Do we have to posit a second evolutionary leap from imagination to symbolization? Or did the event occur at an earlier time – as early as 85,000 years ago – and is it just that the records are lacking (for instance because of the perishable nature of the material)? According to Oppenheimer, a symbolic explosion around 30,000 years ago and located in Europe is much too late to be associated with a fundamental evolutionary event. This was long after modern man spread out over Asia, the Pacific, and Australia, and long after on its route. So, whatever happened must have its roots in an event that occurred before 85,000 years.

Note that it is not inconceivable that a capacity, such as the capacity to symbolize, is present for quite some time before it is put to (extensive) use. However, then one is still intrigued by the question of why. Is it possible to think of a qualitative change that is early, followed by a gradual development that facilitated its use?

Coolidge and Wynn (2005, 2006) make an important connection between established landmark changes in human culture and developments of *working memory*, which they base on Baddeley's (2000, 2001, 2003) Working Memory model. They note that working memory's components have a highly heritable basis, including the phonological storage component. They propose that there may have been an additive genetic neural mutation that led to *enhanced working memory*, which they place in a time frame of between 150,000 and 30,000 years. Their upper bound is consistent with current perspectives on migration, although their lower bound clearly is not. They also note that the idea of a connection between genetic changes and changes in culture has recently been strengthened by the findings of Evans et al. (2005). In that study, the authors found that a genetic variant of the gene microcephalin 1 (or MCPH1), which regulates brain size, increased rapidly in modern humans about 37,000 years ago (95% confidence interval = 14,000–60,000 years). Although no direct effects on neural substrate have been demonstrated so far, a correlation between this gene and an enhanced working memory is tempting. Note, however, that

4 This is on display in the archaeological collection of the Museum in Ulm.

the time frame may pose a problem. The time interval Evans et al. (2005) arrived at is inconsistent with this gene variant's having a major impact on human cognition. For this, it should have occurred before man's exodus out of Africa.

It could be that subsequent research will justify locating this evolutionary event further in the past. An alternative is that it is a change with relatively low impact, just like genetic events leading to diversification of skull types, or dental morphology. Even so, it could be a low-impact event that can only occur as a result of an earlier high-impact event. Clearly, more study is needed before firm conclusions can be drawn, but this line of thought raises intriguing perspectives.

Note that having symbolic behavior is not the same as having language, even if working memory is enhanced. Thus, we have to wonder: What does it take to have a language faculty and to have language?

#### *What does it take to have language?*

As noted in the first section of this chapter, any human language must have a basic vocabulary of lexical items, each item a triple consisting of instructions to the articulatory system (in whatever modality), instructions to the interpretive system (its meaning), and instructions to the grammatical system, together with a combinatory system (and instructions of how to realize and interpret composite elements on the basis of elementary instructions able to derive that *mice chase cats* means something different from *cats chase mice*, although the words are the same).

A crucial step is the disappearance of iconicity. An event in a medium is arbitrarily selected to stand for a (mental representation of) something out there (a thing, a property, an event), or even of something in the mind (a fear, a desire, beauty). Is this again a leap? Or is it an invention, making use of a facility independently given? Strictly speaking, if imagination is given, nothing stops one from imagining that a stretch of sound, or a gesture, stands for a thing or event or emotion. So, the use of icons and non-icons alike may well follow from the trait of being able to imagine a world different from the one that presents itself to the senses.

But, still, this does not give us language. So, what must have happened at the next stage toward language, and why? Interestingly, imagination is an entirely internal affair. It needs no expression in a medium accessible to the outside world. What could then be the selective advantage of non-icons

granted the possession of imagination? We already saw that the ability to carry out efficient computations on models of the world does have a selective advantage. Hence, any means to enhance efficiency of computation will have as well. Non-icons combine a meaning with an arbitrary form. Even within more recent history we have seen the tremendous progress caused by the invention of computing with symbols on the basis of their pure forms instead of their meanings. This ranges from the development of arithmetic to algebra, to formal logics of every degree of sophistication, to the development of generations of electronic computing devices that now seem essential to our lives, and in any case to the societies we live in.

So, if anything is an advantage, certainly the ability of blind computation is. For blind computation we need two ingredients: a vocabulary to compute with and principles allowing us to compute with that vocabulary. As the first ingredient we need non-iconic symbols, but, of course, for reasoning it is unnecessary to pronounce them. In fact, we'd better not, if our computations are to have any effective speed at all. So, we compute with forms in the representation that they have just before being sent off to the SM system: prepackaged (sets of) instructions.

However, to be able to effectively do so, at least one more condition has to be satisfied: these prepackaged instructions must be combinable, not just as instructions, but as elementary units for the combinatory system. Just as the system must temporarily abstain from interpretation, it must also abstain from realization.

Thus, assuming as a first step the possibility for some element  $E_1$  containing instructions for the SM system and the C-I system to be put in a computational space (a working memory), the crucial leap toward having a language-like system is allowing that element not to be sent off immediately to the SM and C-I systems, but allowing it to stay there. Staying there, it must be able to combine with some other element  $E_2$  into a *composite* object of the same kind. It is the "of the same kind" property that allows an iterated combination of elements (merge in the sense of Chomsky 1995 and subsequent work) and the embedding of one partial structure into another partial structure, giving rise to the type of embeddings we see in natural language. According to Chomsky (2005), the recursive property of natural language resides precisely in what he calls the "edge-property" of lexical items: their combinability. This is, then, the minimal change needed to give rise to the type of grammar able to generate a discrete infinity.

This may indeed need only a “simple” rewiring in the sense of Hauser et al. (2002). Thus, in accordance with their perspective, the crucial step, with vast consequences, but simple enough to be instantaneous is this: *the creation of formal mental objects allowing recursion*. What could be the locus of this change? Two possibilities initially present themselves: declarative memory, as the store for lexical items, and working memory, where they are put together. Upon proper consideration, there is a third one, namely the retrieval system, which could have acquired the property of adding an edge feature to elements retrieved. Crucial seems the mode of retrieval. An important feature of the human ability to articulate thoughts consists of the ability to retrieve a concept by its form. Note also that a form is nothing but an encoded instruction for realization, which allows being manipulated, whereas realization – that is, sending off the instruction – is being postponed. It seems to me that *being able to retrieve a concept by its form and allowing it to stay in working memory while some other element is being retrieved* is extremely close, perhaps equivalent, to having a so-called edge feature.

Like with all such issues, the question of what gave rise to it seems hard to resolve. Nevertheless, one can ask, is there a known genetic event that could potentially be associated with it? To cut a long story short, yes, perhaps there is, namely in the most recent mutation of the FOXP2 gene. To give the shortest possible version, Vargha-Khadem et al. (1995, 1998) report that this gene plays an important role in the human articulatory system (although not exclusively there).<sup>5</sup> Very similar variants of this gene are found in other animals, from birds to mice, and also play a role there in the systems for vocalization. The gene is evolutionarily very stable. According to Enard et al. (2002), in 75 million years since the split between mouse and chimpanzee, only one change has occurred in FOXP2. However, in the 6 million years since the split of man and chimpanzee, two changes have occurred in the human lineage. Enard et al. estimate that the mutations in the FOXP2 gene in the human lineage occurred between 10,000 and 100,000 years ago. They speculate that the mutations have been critical for the development of human speech as we understand it and also critical for the development of human cognition. The upper segment of their time frame is consistent with the factors discussed so far. The question, though,

<sup>5</sup> Their report is based on their investigation of hereditary linguistic disabilities in the Khe family, a family in which this gene has been found to be damaged.

is this: How could a mutation in this gene be relevant? Clearly a mere fine tuning of our articulatory apparatus would be far from sufficient to produce the effects Enard et al. would like to derive. However, there is one aspect of control over the articulatory apparatus that would be enough, namely the control to postpone realization (or even to not realize at all), the control to retrieve by form, and the control to combine by form.

Interestingly, under this scenario the event giving rise to the formal combinatory system is dissociated from whatever event shaped and enhanced working memory. Note that the crucial change on the form side may well be independent of the fine tuning of our articulatory system, even if the same gene is involved. This need not be controversial, because this gene could find different expression in different subsystems, as genes generally do.

### From language faculty to language

The adaptive value of language thus conceived can be expected to be substantial. It goes far beyond what would follow from its referential use. A crucial property of language is that it subserves reasoning, as it allows the drawing of inferences and fast assessment of possible states of affairs. Its profit may also involve communication, but to some extent also indirectly, because the results of reasoning may be far more important to communicate than what one sees, feels, or smells.

It is, in fact, conceivable that all the ingredients for language are in place, that “language” as an internal, mental computational system is already in use and is even providing an evolutionary advantage, but that there is as yet no language in the sense as we know now – that is, that what there is, is not yet used for intersubject communication.

This scenario introduces a sharp and principled distinction between Stage 2, the genesis of the language faculty, and Stage 3, the actual emergence of language as a communicative system based on a shared code, embedded in a social community. This links our discussion to a recurrent theme in the literature on the evolution of language: *Was the emergence of (the) language (faculty) instantaneous or gradual?*

This issue is crucial for claims that special forms of language may serve as windows to its evolution. Therefore, we find discussion of the role of “degraded” language and spontaneous languages (sign language) by Jackendoff (1999, 2002), motherese (Falk 2004), or about so-called transitional stages or protolanguages (Arbib 2005). In discussions of degraded or

Protolanguages, it is generally assumed that they lack some standard design features of canonical human language. For instance, they are said to lack recursion, functional categories, and dislocation. But what warrants treating actual degraded languages as providing a view on the past? It seems to me that this depends on either of two assumptions.

1. Language evolution took place gradually; current design features were added in separate steps. If so, degraded language forms could exemplify stages of language in which certain design features were still missing.
2. Once the language faculty (edge features on lexical items) was in place, it still took mankind a significant period of time to discover its full significance; in other words, language as we know it has a significant cultural component that goes beyond the cultural basis of the lexicon. If so, degraded language forms exemplify stages of language in which certain design features were not yet being used.

Again, it is crucial to distinguish between the “language faculty” and “language as we know it.” For the language faculty, a recursive procedure on formally represented mental entities is constitutive. So, in this sense, recursion cannot be missing. Because recursion is either available or it is not, we have a sharp cutoff point. Note that, before that stage, we may have extensive manipulation of internal representations of the world, iconic symbols and the like, but these are constitutive of an earlier step, the introduction of imagination, and its full exploitation. Nevertheless, even if at some time the language faculty was in place, it may yet have taken our ancestors some more time to discover and explore its potential.

Once the language faculty was there, and being in full use, one may wonder what limitations would still have to be overcome for it to yield a language of the type as we know it. If, in accordance with Coolidge and Wynn (2005), working memory was more limited in the early stages than it is nowadays, this might have had an effect on the *use* of some features of language, for instance long-distance dependencies, but not necessarily on their *existence*. Once we have a computational system, we must again sharply distinguish between the type of computations it allows and the computations that are actually performed.

Consider dislocation. For instance, in a free-word-order language such as Russian, each order reflects its own contribution to information structure. This is illustrated in examples 2–4, taken from Slioussar (2007).

- (2) a. Programmist kupil kofevarku.  
 programmer.NOM bought [coffee machine].ACC  
 b. Kofevarku kupil programmist.  
 [coffee machine].ACC bought programmer.NOM

The meaning of two sentences is the same. Yet, they cannot be used in the same contexts, as shown in examples 3 and 4:

- (3) a. Naš novyj ofis bystro obustraivalsja.  
 “Our new office was settled in very fast.”  
 b. Programmist kupil kofevarku. = (2a)  
 c. # Kofevarku kupil programmist. = (2b)
- (4) a. Vskore v novom ofise pojavilis’ čajnik, kofevarka i toster.  
 “Before long, there were a kettle, a coffee machine and a toaster in the new office.”  
 b. # Programmist kupil kofevarku. = (2a)  
 c. Kofevarku kupil programmist. = (2b)

The difference between examples 2a and 2b is in the way they present, or structure, the information contained in them. Simplifying a bit, the “OVS” sentence in example 2b presents the object as given in the context and the subject as new information.

In the conception of Chomsky (2004a, 2004b), the role of dislocation is precisely to relate discourse-related properties such as old and new information, and specificity to argument structure. By themselves, such properties of information are independent of language. Any of our ancestors who had some sense of time and temporal organization should be able to represent such properties in one way or other. The computational system in its barest form gives dislocation for free, in the form of “internal merge”: merge an element that is already in the expression under construction, just like you can merge an element directly from the mental lexicon. Hence, one does not expect to find an actual degraded language without dislocation, nor a protolanguage that deserves the name without it.

Nevertheless, a more limited working memory might lead to a different balance in the use of dislocation, because the relation between each dislocated element and its canonical position has to be computed. Reconstruction of the canonical relationships requires the ability to hold a certain amount of material in working memory. If resources are insufficient, then this may well result in striking a different balance.

Stressing this issue again, let us say that linguistic computations do not take place in a vacuum. So, naturally, properties of the systems subserving language (its neural substrate) enter into the equation if one studies language processing. The question is to what extent also properties of the grammatical system reflect the need to optimally use linguistic processing resources. For instance, Chomsky (2001) proposes that natural language computations systematically operate chunk by chunk. Such chunks are called *phases* in current grammatical terminology. Without going into details, one can say that one such chunk (the v\*-phase) is the part of the sentence that represents the core predicate structure, a verb with all its arguments. The other chunk (the C-phase) is the structure reflecting the way it is anchored to the temporal system, information structure, and its force as a question, command, or declaration. So the question is this: What motivates this chunking, and the particular way it is realized in grammar? Is it computational efficiency *tout court*? This would require computational proof that a system with precisely these two phases is computationally optimal.

The alternative is that limitations on processing resources or working memory require the regular sending off of material to other components for further processing, where it becomes inaccessible for syntactic operations. If so, we have a rationale for this selection of phases, because what is sent off better be useable without additional work and be put together again after having been separated by this chunking process, namely the core predicate – a bare proposition – and the instructions for enriching its interpretation.

On the interpretive side, this indeed leads to an advantage for argument-complete material (the v\*-phase) and functionally complete material (the C-phase). In Chomsky's system, it is only the most peripheral position in a phase (its *edge*) that remains accessible. Functionally, these can be understood as the joints to put the pieces together again after having been handed over to the interpretive system.

This line of thought links the limitations on processing resources to linguistic functionality: The biological bound on working memory stretches linguistic functionality to its limits. The minimally useful message part gets zipped so as to fit into working memory.

## Conclusion

From an evolutionary perspective, this idea leaves room for a gradual expansion of linguistic expressive means once the basic principles of language

are in place. For instance, an increase in processing resources may have a general advantage in terms of speed of computing alternatives to the current state of affairs and of how to get there. However, an increase in processing resources may also facilitate handling more complex structures and allow more explicitness in expression. If so, “experiments of nature” leading to a reduction of processing resources<sup>6</sup> could provide a window on language evolution, but only in a limited sense: Not as a window on the emergence of the language-ready mind, or on any protolinguistic situation, but only as a window on a possible state of affairs after the emergence of language, but before the development of an enhanced working memory.

<sup>6</sup> For instance, one such item would a brain lesion leading to agrammatic aphasia, which Kolk (1995, 1998) and Avrutin (2000, 2001) convincingly show to reflect a limitation on processing resources.

## CHAPTER 13

# Whither evolutionary cognitive archaeology? Afterword

*Thomas Wynn*

Evolutionary cognitive archaeology (ECA) remains a largely inchoate amalgam of approaches. As the chapters of this volume demonstrate, an eclectic array of interests, methods, and theories are able to lay claim to the cognitive label. They do share one common thread: The conviction that prehistoric minds structured prehistoric action, and that archaeology has access, albeit limited, to those minds. Beyond this, little unites the chapters. However, there are recurrent themes that suggest ways in which ECA may soon coalesce into a more coherent and powerful approach.

### Theory

ECA is perhaps most eclectic at the level of theory. Many understandings of the nature of mind have been applied to the evolutionary record, but three have been especially influential in ECA. The first, and oldest, is the idea that modern syntactical language is the key to the modern mind. Theoretical roots to this notion go deep into the history of Western philosophy, but its current incarnation traces back to the Chomskian revolution in linguistics, and its subsequent influence on anthropological thinking in the United States (the irony here is that Chomsky himself eschews the idea of language evolution altogether!). For American archaeologists trained in anthropology departments in the 1970s and 1980s, language is the *sine qua non* of humanness, with other cognitive abilities being only secondary in importance (see, e.g., the chapter by Tattersall, and to a lesser extent those of Reuland, Walker, and Uomini). The second theoretical stance is the action-centered approach of Leroi-Gourhan. In *Le Geste et la Parole* (1964), Leroi-Gourhan developed a powerful alternative to the linguistic model of

the mind, which grants importance to the context of action and views cognition as something that emerges from the interaction of the individual actor and the task at hand. Leroi-Gourhan has been especially influential in Francophone ECA, where his ideas have also grounded the development of what is arguably the most powerful method in the ECA toolkit (see the chapters by Haidle and Pelegrin). The third prevailing theoretical stance has been borrowed whole cloth from developmental and cognitive psychology (see also the chapter by Maestro and Collina). It conceives of the mind as consisting of internal computational states or “representations” that model and guide action. These approaches situate cognition squarely in the heads of the actors, and most advocates consider cognition to be reducible, ultimately, to brain function. Variations of this third position underpin an immense literature in psychology and neuroscience, and they constitute a fertile source of interpretive concepts (examples in this volume include the chapters by de Beaune, Kyriacou, Rossano, Uomini, Walker, and Wynn and Coolidge). There is a fourth, currently popular approach to the mind that has not gained much traction in ECA – the stance taken by evolutionary psychologists, who treat the mind as an immense collection of narrow computational modules, largely or entirely unconscious, that each evolved to solve a narrow evolutionary problem. Its unpopularity in ECA stems from its sole reliance on reverse engineering (a method long held suspect by archaeologists), and its cultivated ignorance of the palaeoanthropological record.

In their purest forms, the three leading theoretical understandings (linguistic, action oriented, and representational) are largely incompatible, but in the more practical world of application to the evolutionary record the three do overlap, as several of the current chapters demonstrate. The linguistic approach can be reconciled with a representational approach, as can the action-centered approach. However, few archaeologists have done this explicitly, and the three approaches remain mostly independent. This may soon change. All understandings of the nature of mind have begun to take account of developments in neuroscience, and it is in the domain of cognitive neuroscience that ECA appears most likely to coalesce into a coherent discipline. Over the past 20 years, neuroscience has made great strides in understanding how the brain works, and, although it will be a long time before scholars can dispense with behavioral models of the mind entirely, it is now foolish (or hubristic) to ignore what is known about the brain. Neural insights into behavior extend from the smallest components

(chemical neurotransmitters) to the largest (gross anatomical structures such as the cerebellum). Neuroimaging techniques (such as positron emission tomography, functional magnetic resonance imaging, and electroencephalography) now permit links to be drawn between anatomy, neural activation, and behavior. It is no longer overly optimistic to predict that an understanding of the brain will eventually resolve the roles of language, action, and representation in the evolution of the human mind itself, and empower closer cooperation between archaeologists, human palaeontologists, and neuroscientists.

## Methods

Two methods dominate ECA. The first interprets the final products of prehistoric activity and is largely an extension of typological approaches that characterized palaeolithic archaeology for most of the twentieth century. The second focuses on reconstructed sequences of action – *chaînes opératoires* – rather than the products themselves. Both methods have provided valuable insights, but it is the second that may hold the greatest potential.

A focus on final products has several now well-known inherent drawbacks for the cognitive approach. The first is equifinality. Often several different actions or procedures will produce similar or even identical products. When this happens, archaeologists must fall back on “minimum competence” and conclude that the simplest procedure was the one responsible, unless of course some independent evidence points to a more complex procedure. As a result, there is always a risk of underassessing prehistoric abilities. A second problem is that of the “finished artifact fallacy” and the related problem of documenting “mental templates” (Davidson & Noble 1993). It is often very difficult to know if an artifact represents some prehistoric intention or was simply the point in the use-life of the artifact when it was lost or discarded. It is even more difficult to demonstrate that an artifact existed as an image in prehistoric consciousness, that is, a mental template. Both the finished artifact fallacy and the assumption of mental templates arise from the inappropriate use of traditional typologies to reach cognitive conclusions. Types such as “handaxe” or “split-based point” were not initially defined with cognition in mind, and they have no inherent cognitive implications. If cognitive archaeologists want to use products of action as evidence for minds, it is necessary that they define explicitly which attributes carry

cognitive implications (Wynn 2002). This is perhaps the only indispensable step in a cognitive analysis.

Describing *chaînes opératoires* has several distinct advantages over the final product approach (see also the chapter by Maestro and Collina). First, by describing sequences of action, it sidesteps most of the problems of equifinality; second, because it focuses on action sequences, it also avoids the baggage of the typological approach. The greatest advantage, though, is a third: A *chaîne opératoire* is a far richer data set for cognitive interpretation than a simple artifact, or even an assemblage of artifacts (see the chapter by Miriam Haidle for a prime example). A *chaîne opératoire* documents a sequence of decisions actually made by a prehistoric actor, and such decision sequences are loaded with cognitive implications. As a method, it has provided some of our most comprehensive pictures of prehistoric minds in action, such as the masterful documentation of the Lokalalei *chaînes opératoires* by Delagnes and Roche (2005; see the chapter by Pelegrin, this volume). Despite its great potential, this approach has been retarded by two rather different problems. First, there appears to be no consensus about how to describe, present, and quantify *chaînes opératoires*. Most practitioners use an idiosyncratic system, making direct comparison difficult. Second, many of the practitioners expect that the *chaînes opératoires* will speak for themselves. They do not. Interpretation still requires an explicit basis in a theory of cognition. In the example just cited, Delagnes and Roche make a convincing case for a difference in the complexity of the action sequences at Lokalalei 1 and Lokalalei 2C, but they pursue the implications no further. Complexity is just not a well-defined cognitive concept. Yes, Delagnes and Roche have documented something very important, but if they could inform their result with a coherent theory of cognition, something much more powerful might emerge.

### Not telling the tale

ECA as a whole remains uncertain about its role in the discourse of evolutionary studies, but this too is changing. For over 40 years now palaeolithic archaeology has been dominated by an adaptationist program, one of whose themes has been the triumph of ecological-cultural adaptations in the evolution of hominins, and, ultimately, in the ascendancy of *Homo sapiens*. The result is a biocultural tale of struggle, failure, and success, most often fleshed out in the guise of hunting and gathering groups living on past

landscapes, competing with carnivores, coping with climate change, and adjusting to population growth and movement, even the arrival of new species of hominin. ECA has occasionally contributed to this narrative, as when it contrasts *Homo erectus* cognition with that of earlier *Homo*, or modern humans with Neanderthals. In this respect ECA simply provides new detail to a story that has already largely been written. This is a derivative role; ECA can be much more. It can, in fact, play a direct role in cognitive science.

Of the various disciplines investigating the evolution of cognition, ECA is the only one that is able to document actual cognitive events that occurred in the past. Comparative and other neontological approaches, including those of evolutionary psychology, can only make predictions from modern evidence. However fragmentary it might be, the archaeological record was initially produced in the past by ancient minds; it is, therefore, invaluable. But, to contribute to the evolutionary branch of cognitive science, ECA must concentrate on well-defined cognitive abilities. Many of the chapters in the present volume take this course. Handedness, working memory, skill, theory of mind, and even consciousness and innovation are narrower, more manageable domains than vague allusions to intelligence or modern minds. When ECA treats cognition as a set of distinct cognitive abilities, an important and not altogether surprising pattern emerges. Cognitive evolution appears to have been mosaic. Some components of modern cognition evolved long ago (spatial cognition; handedness, perhaps), some very recently (enhanced working memory and, perhaps, consciousness), and some sprinkled in between (symbolic reference, skill, theory of mind, allocentric perception). ECA has only just begun to trace the pattern of this mosaic, and much is unclear (e.g., innovation by analogy, which de Beaune argues emerged early, but Wynn and Coolidge argue was a late development). However, a second conclusion already appears warranted: Human cognitive evolution does not map easily onto the traditional units of palaeoanthropology. Significant developments *did* occur during the Acheulean; from a cognitive perspective, the initial Upper Palaeolithic resembles the Middle Palaeolithic more than it resembles the late Upper Palaeolithic. There will undoubtedly be other surprises. To be sure, ECA will continue to enrich traditional culture historic scenarios (e.g., the fate of Neanderthals), but this is not how it should be judged. Rather, ECA should be judged on the basis of what it reveals about the evolution of the human mind itself.

## References

- Adams, J. L. 1991. *Flying buttresses, entropy and o-rings*. Cambridge, MA: Harvard University Press.
- Aiello, L. C. 1998. The foundation of human language. In N. G. Jablonski & L. C. Aiello (Eds.), *The origin and diversification of language* (pp. 21–34). San Francisco: California Academy of Science.
- Aiello, L. & Dunbar, R. 1993. Neocortex size, group size and the evolution of language. *Current Anthropology*, 34, 184–193.
- Alimen, M.-H. & Goussard, M. 1962. Le développement de l'intelligence et les structures paléopsychologiques. *Bulletin de la Société préhistorique française*, 59, 386–406.
- Ambrose, S. 1998. Late Pleistocene human population bottlenecks, volcanic winter, and differentiation of modern humans. *Journal of Human Evolution*, 34, 623–651.
- Annett, M. 2002. *Handedness and brain asymmetry: The right shift theory*. Hove, UK: Psychology Press.
- Arbib, M. A. 2005. From monkey-like action recognition to human language: An evolutionary framework for neurolinguistics. *Behavioral and Brain Sciences*, 28, 105–124.
- Armstrong, M. S. & McConaghy, N. 1977. Allusive thinking, the word halo and verbosity. *Psychological Medicine*, 7, 439–445.
- Ashton, N. & White, M. 2003. Bifaces and raw materials: Flexible flaking in the British Early Paleolithic. In M. Soressi & H. L. Dibble (Eds.), *Multiple approaches to the study of bifacial technology* (pp. 109–124). Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.
- Athènes, S., Sallagolty, I., Zanone, P.-G., & Albaret, J.-M. 2004. Evaluating the coordination dynamics of handwriting. *Human Movement Science*, 23, 621–641.
- Avrutin, S. 2000. Language acquisition and language impairment: A comparative psycholinguistic approach. *Brain and Language*, 71, 7–9.
- Avrutin, S. 2001. Linguistics and agrammatism. *GLOT International*, 5, 3, 1–11.
- Baddeley, A. D. 2000. The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417–423.

- Baddeley, A. D. 2001. Is working memory working? *American Psychologist*, 11, 851–864.
- Baddeley, A. D. 2003. Working memory and language: An overview. *Journal of Communication Disorders*, 36, 189–208.
- Baddeley, A. & Hitch, G. J. 1974. Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (pp. 47–90). New York: Academic Press.
- Baddeley, A. & Logie, R. 1999. Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working: Mechanisms of active maintenance and executive control* (pp. 28–61). Cambridge, UK: Cambridge University Press.
- Balter, M. 2000. Paintings in Italian cave may be oldest yet. *Science*, 290, 419–421.
- Banich, M. T. 1995. Interhemispheric processing: Theoretical considerations and empirical approaches. In R. J. Davidson & K. Hugdahl (Eds.), *Brain asymmetry* (pp. 427–450). Cambridge, MA: The MIT Press.
- Barham, L. 2007. Modern is as modern does? Technological trends and thresholds in the south-central African record. In P. Mellars, K. Boyle, O. Bar Yosef, and C. B. Stringer (Eds.), *Rethinking the human revolution: New behavioural and biological perspectives on the origin and dispersal of modern humans* (pp. 165–176). Cambridge, UK: McDonald Institute for Archaeological Research.
- Barker, G., H. Barton, M. Bird, P. Daly, I. Datan, A. Dykes, L. Farr, D. Gilbertson, B. Harisson, C. Hunt, T. Higham, L. Kealhofer, J. Krigbaum, H. Lewis, S. McLaren, V. Paz, A. Pike, P. Piper, B. Pyatt, R. Rabett, T. Reynolds, J. Rose, G. Rushworth, M. Stephens, C. B. Stringer, J. Thompson, and C. Turney. 2007. The ‘human revolution’ in lowland tropical Southeast Asia: The antiquity and behaviour of anatomically modern humans at Niah Cave (Sarawak, Borneo). *Journal of Human Evolution* 52, 243–261.
- Barkley, R. 2001. The executive functions and self-regulation: An evolutionary neuropsychological perspective. *Neuropsychology Review*, 11, 1–29.
- Barkow, J., Cosmides, L., & Tooby, J. 1992. *The adapted mind: Evolutionary psychology and the generation of culture*. New York: Oxford University Press.
- Barrantes-Vidal, N. 2004. Creativity and madness revisited from current psychological perspectives. *Journal of Consciousness Studies*, 11, 58–78.
- Bar Yosef, O. 2006. Between observations and models: An eclectic view of Middle Paleolithic Archaeology. In E. Hovers & S. L. Kuhn (Eds.), *Transitions before the transition* (pp. 305–325). New York: Springer.
- Beck, B. B. 1980. *Animal tool behavior. The use and manufacture of tools by animals*. New York: Garland STPM Press.
- Bednarik, R. 1994. A taphonomy of palaeoart. *Antiquity*, 68, 68–74.
- Belfer-Cohen, A. & Goren-Inbar, N. 1994. Cognition and communication in the Levantine Lower Palaeolithic. *World Archaeology*, 26, 144–157.
- Bellomo, R. 1994. Methods of determining early hominid behavioral activities associated with the controlled use of fire at Fxj 20 Main, Koobi Fora, Kenya. *Journal of Human Evolution*, 27, 173–195.

- Berlim, M. T., Mattevi, B. S., Belmonte de Abreu, P., & Crow, T. J. 2003. The etiology of schizophrenia and the origin of language: Overview of a theory. *Comprehensive Psychiatry*, 44, 7–14.
- Beyries, S. & Joulain, F. 1990. L'utilisation d'outils chez les animaux. Chaînes opératoires et complexité technique. *Paléo*, 17–26.
- Biddittu, L. & Segre, A. G. 1982. Utilizzazione dell'osso nel Paleolitico inferiore italiano. Atti della xxiii Riunione Scientifico dell'Istituto italiano di Preistoria e Protohistoria, Firenze, 1980, 89–105.
- Binford, L. R. & Ho, C. K. 1985. Taphonomy at a distance: Zhoukoudian, "The cave home of Beijing man"? *Current Anthropology*, 26, 413–442.
- Bingham, P. M. 1999. Human uniqueness: A general theory. *The Quarterly Review of Biology*, 74, 133–169.
- Bischof-Koehler, D. 2006. Theory of mind and mental time travel: Specifically human abilities. Paper presented at the Second Biennial Conference on Cognitive Science, June 9–13, 2006, St. Petersburg, Russia.
- Black, D., Young, C. C., Pei, W. C., & de Chardin, T. 1933. *Fossil man in China*. Memoirs of the Geological Survey of China (Series A 11).
- Bleed, P. 1986. The optimal design of hunting weapons: Maintainability or reliability? *American Antiquity*, 51, 737–747.
- Boë, L.-J. & Iranzo, P. 1994. *Invention médiatique et découverte scientifique. Un sérieux cas d'amnésie vocale*. Grenoble: Institut de la Communication Parlée (Monograph).
- Boëda, E. 1986. *Approche technologique du concept Levallois et évaluation de son champ d'application. Étude de trois gisements saaliens et weichséliens de la France septentrionale*. PhD dissertation, Université Paris X, Nanterre.
- Boëda, E. 1991. Approche de la variabilité des systèmes de production lithique des industries du Paléolithique inférieur et moyen. Chronique d'une variabilité attendue. *Techniques et Culture*, 17–18, 37–79.
- Boëda, E. 1994. *Le concept Levallois. Variabilité des méthodes*. Paris: CNRS Éditions (Monographie du CRA 9).
- Boëda, E. 1995. Levallois: A volumetric construction, methods, a technique. In H. L. Dibble & O. Bar Yosef (Eds.), *The definition and interpretation of Levallois technology* (pp. 41–68). Madison, WI: Prehistory Press (Monographs in World Archaeology 23).
- Boëda, E. 2001. Les techniques des hommes de la préhistoire pour interroger le présent. Septième École d'été de l'ARCo, Cours d'Éric Boëda, July 10–21, 2000, Bonas.
- Boëda, E. 2005. Paléo-technologie ou anthropologie des techniques?, *Arob@se*, [www.univ-rouen.fr/arobase](http://www.univ-rouen.fr/arobase), 1, 46–64.
- Boëda, E., Geneste, J.-M., & Meignen, L. 1990. Identification de chaînes opératoires du Paléolithique ancien et moyen. *Paléo*, 43–88.
- Boëda, E. & Pelegrin, J. 1979–1980. Approche technologique du nucléus Levallois à éclat. *Études Préhistoriques*, 15, 41–48.

- Bogen, J. E. & Bogen, G. M. 1969. The other side of the brain III: The corpus callosum and creativity. *Bulletin of the Los Angeles Neurological Societies*, 34, 191–203.
- Boëcinelli, E. 2005. Language origin between adaptation and exaptation. *Lingue e Linguaggio*, IV.1, 121–127.
- Bordes, F. 1947. Étude comparative des différentes techniques de taille du silex et des roches dures. *L'Anthropologie*, 51, 1–29.
- Bordes, F. 1970. Réflexions sur l'outil au Paléolithique. *Bulletin de la Société préhistorique française*, 67, 199–202.
- Bordes, F. 1971. Physical evolution and technological evolution in man: A parallelism. *World Archaeology*, 3, 1–5.
- Borghi, A. & Iachini, T. 2002. *Scienze della mente*. Bologna: Il Mulino.
- Botha, R. 2006. On the windows approach to language evolution. *Language & Communication*, 26, 129–143.
- Bounak, V. V. 1959. L'origine du langage. In *Les processus de l'homínisation* (pp. 99–111). Paris: CNRS Éditions.
- Bradshaw, J. L. 1997. *Human evolution. A neuropsychological perspective*. New York: Psychology Press.
- Bradshaw, J. L. & Rogers, L. J. 1993. *The evolution of lateral asymmetries, language, tool use, and intellect*. San Diego: Academic Press.
- Brain, C. K. & Sillen, A. 1988. Evidence from the Swartkrans cave for the earliest use of fire. *Nature*, 336, 464–466.
- Bresson, F. 1992. Aptitude au langage chez les Néandertaliens. Apport d'une approche pluridisciplinaire. *Bulletins et Mémoires de la Société d'Anthropologie de Paris*, n.s., 4, 1–2, 33–51.
- Bril, B., Roux, V., & Dietrich, G. 2005. Stone knapping: Khambhat (India), a unique opportunity? In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 53–71). Cambridge, UK: McDonald Institute for Archaeological Research.
- Brinton, D. G. 1896. Left-handedness in North American Aboriginal art. *American Anthropologist*, IX, 175–181.
- Broca, P. P. 1861. Perte de la parole, ramollissement chronique et destruction partielle du lobe antérieur gauche du cerveau. *Bulletin de la Société Anthropologique*, 2, 235–238.
- Brooks, A. S., Nevell, L., Yellen, J. E., & Hartman, G. 2006. Projectile technologies of the African MSA: Implications for modern human origins. In E. Hovers & S. L. Kuhn (Eds.), *Transitions before the transition* (pp. 233–255). New York: Springer.
- Bruner, E. 2003. Fossil traces of the human thought: Paleoneurology and the evolution of the genus *Homo*. *Journal of Anthropological Sciences*, 81, 29–56.
- Bryden, M. P. 1977. Measuring handedness with questionnaires. *Neuropsychologia*, 15, 617–624.
- Burling, R. 1986. The selective advantage of complex language. *Ethology and Sociobiology*, 7, 1–16.

- Byrne, R. 1995. *The thinking ape. Evolutionary origins of intelligence*. Oxford: Oxford University Press.
- Cahen, D., Keeley, L. H., & Van Noten, F. L. 1979. Stone tools, toolkits, and human behavior in prehistory. *Current Anthropology*, 20, 661–683.
- Calabretta, R. 2002. Connessionismo evolutivo e origine della modularità. In A. Borghi & T. Iachini (Eds.), *Scienze della mente* (pp. 47–63). Bologna: Il Mulino.
- Calabretta, R. & Parisi, D. 2005. *Evolutionary connectionism and mind/brain modularity*. In W. Callebaut & D. Rasskin-Gutman (Eds.), *Modularity. Understanding the development and evolution of complex natural systems* (pp. 309–330). Cambridge, MA: The MIT Press.
- Callahan, E. 1979. The basics of biface knapping: A manual for flint knappers and lithic analysis. *Archaeology of Eastern North America*, 7, 1–79.
- Carlsson, I., Wendt, P. E., & Risberg, J. 2000. On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. *Neuropsychologia*, 38, 873–885.
- Carruthers, P. & Chamberlain, A. 2000. *Evolution and the human mind. Modularity, language and meta-cognition*. Cambridge, UK: Cambridge University Press.
- Carter, O. L., Presti, D. E., Callistemon, C., Ungerer, Y., Lui, G. B., & Pettigrew, J. D. 2005. Meditation alters perceptual rivalry in Buddhist monks. *Current Biology*, 15, R412.
- Cashmore, L., Uomini, N. & Chapelain, A. 2008. The evolution of handedness in humans and great apes: a review and current issues. *Journal of Anthropological Sciences* 86: 7–35.
- Cauvin, J. 1978. *Les Premiers Villages de Syrie-Palestine du ix<sup>e</sup> au vi<sup>e</sup> millénaire avant Jésus-Christ*. Lyon: Travaux de la Maison de l'Orient 4 (Série archéologique 3).
- Cauvin, J. 1994. *Naissance des divinités. Naissance de l'agriculture*. Paris: CNRS Éditions.
- Changeux, J.-P. 2000. In J.-P. Changeux & P. Ricœur, *Ce qui nous fait penser. La Nature et la règle*. Paris: Odile Jacob.
- Charness, N., Krampe, R., & Mayr, U. 1996. The role of practice and coaching in entrepreneurial skill domains: An international comparison of life-span chess skill acquisition. In K. A. Ericsson (Ed.), *The road to excellence* (pp. 51–80). Mahwah, NJ: Erlbaum.
- Chiarello, C., Burgess, C., Richards, L., & Pollock, A. 1990. Semantic and associative priming in the cerebral hemispheres: Some words do, some words don't, . . . sometimes, some places. *Brain and Language*, 38, 75–104.
- Chomsky, N. 1995. *The minimalist program*. Cambridge, MA: The MIT Press.
- Chomsky, N. 1998. *Minimalist inquiries: The framework*. Cambridge, MA: The MIT Press (MIT Occasional Papers in Linguistics 15).
- Chomsky, N. 2001. *Derivation by phase*. In M. Kenstowicz (Ed.), *Ken Hale: A life in language* (pp. 1–52). Cambridge, MA: The MIT Press.

- Chomsky, N. 2004a. Beyond explanatory adequacy. In A. Belletti (Ed.), *Structures and beyond*. Oxford: Oxford University Press.
- Chomsky, N. 2004b. Lectures presented at the Conference on Tools in Linguistic Theory (TiLT), May 16–18, 2004, Budapest, Institute of Linguistics Hungarian Academy of Sciences/Utrecht Institute of Linguistics OTS.
- Chomsky, N. 2005. *On phases*. Cambridge, MA: The MIT Press.
- Clegg, F. 1982. *Simple statistics: A course book for the social sciences*. Cambridge, UK: Cambridge University Press.
- Cocude, M. & Jouhaneau, M. 1993. *L'Homme biologique*. Paris: Presses Universitaires de France.
- Collard, M. 2002. Grades and transitions in human evolution. In T. J. Crow (Ed.), *The speciation of modern Homo sapiens* (pp. 61–100). Oxford: Oxford University Press.
- Commont, V. 1913. Les hommes contemporains du renne dans la vallée de la Somme. *Mémoires de la Société des Antiquaires de Picardie*, 37, 207–646.
- Coolidge, F., Thede, L., & Young, S. 2001. Heritability and the comorbidity of ADHD with behavioral disorders and executive function deficits: A preliminary investigation. *Developmental Neuropsychology*, 17, 273–287.
- Coolidge, F. & Wynn, T. 2001. Executive functions of the frontal lobes and the evolutionary ascendancy of *Homo sapiens*. *Cambridge Archaeological Journal*, 11, 255–260.
- Coolidge, F. & Wynn, T. 2005. Working memory, its executive functions, and the emergence of modern thinking. *Cambridge Archaeological Journal*, 15, 5–26.
- Coolidge, F. L. & Wynn, T. 2006. Recursion, pragmatics, and the evolution of modern speech. Paper presented at the Cradle of Language Conference, November 6–10, 2006, Stellenbosch, South Africa.
- Corballis, M. C. 1989. Laterality and human evolution. *Psychological Review*, 96, 3, 492–505.
- Corballis, M. C. 1998. Evolution of language and laterality: A gradual descent? *Cahiers de Psychologie Cognitive/Current Psychology of Cognition*, 17, 1148–1155.
- Corballis, M. C. 2002. *From hand to mouth: The origins of language*. Princeton, NJ: Princeton University Press.
- Corballis, M. C. 2005. From mouth to hand: Gesture, speech, and the evolution of right-handedness. *Behavioral & Brain Sciences*, 26, 199–208; commentaries & reply, 208–242; references, 250–260.
- Cornford, J. M. 1986. Specialized resharpening techniques and evidence of handedness. In P. Callow & J. M. Cornford (Eds.), *La Cotte de St. Brelade 1961–1978: Excavations by C.B.M. McBurney* (pp. 337–351, 413–414). Norwich: Geo Books.
- Crabtree, D. 1972. *An introduction to flintworking*. Pocatello: Idaho State University (Occasional Papers 28).
- Crompton, R. H. & Gowlett, J. A. J. 1993. Allometry and multidimensional form in Acheulean bifaces from Kilombe, Kenya. *Journal of Human Evolution*, 25, 175–199.

- Crow, T. J. 1997a. Schizophrenia as failure of hemispheric dominance for language. *Trends in Neuroscience*, 20, 339–343.
- Crow, T. J. 1997b. Schizophrenia as the price that *Homo sapiens* pays for language: A resolution of the central paradox in the origin of the species. *Schizophrenia Research*, 28, 127–141.
- Crow, T. J. 2004. Cerebral asymmetry and the lateralization of language: Core deficits in schizophrenia as pointers to the gene. *Current Opinion in Psychiatry*, 17, 97–106.
- Cushing, F. H. 1892. Manual concepts: A study of the influence of hand-usage on culture-growth. *American Anthropologist*, 5, 289–318.
- Damasio, A. R. 1994. *Descartes' error. Emotion, reason and the human brain*. New York: Crosset-Putnam & Avon.
- Davidson, I. & Noble, W. 1993. Tools and language in human evolution. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognition in human evolution* (pp. 363–388). Cambridge, UK: Cambridge University Press.
- Deacon, H. 1993. Planting an idea: An archaeology of Stone Age gatherers in South Africa. *South African Archeological Journal*, 48, 86–93.
- Deacon, T. 1997. *The symbolic species: The co-evolution of language and the brain*. New York: W. W. Norton.
- de Beaune, S. A. 2000. *Pour une archéologie du geste. Broyer, moudre, piler, des premiers chasseurs aux premiers agriculteurs*. Paris: CNRS Éditions.
- de Beaune, S. A. 2002. Commentary on D. Stout, skill and cognition in stone tool production: An ethnographic case study from Irian Jaya. *Current Anthropology*, 43, 716.
- de Beaune, S. A. 2004. The invention of technology: Prehistory and cognition. *Current Anthropology*, 45, 139–162.
- de Beaune, S. A. 2008. *L'homme et l'outil. L'invention technique durant la préhistoire*. Paris: CNRS Éditions.
- Deforge, Y. 1994. L'évolution des objets techniques. In Gilbert Simondon. *Une pensée de l'individuation et de la technique* (pp. 173–181). Paris: Albin Michel (Bibliothèque du Collège international de philosophie).
- Dehaene, S. (Ed.), 2001. *The cognitive neuroscience of consciousness*. Cambridge, MA: The MIT Press.
- Dehaene, S. 2003. Les bases cérébrales d'une acquisition culturelle. La lecture. In J.-P. Changeux (Dir.), *Gènes et culture* (pp. 187–199). Paris: Odile Jacob (Symposium annuel du Collège de France).
- Delagnes, A. & Roche, H. 2005. Late Pliocene hominid knapping skills: The case of Lokakalei 2C, West Turkana, Kenya. *Journal of Human Evolution*, 48, 435–472.
- de Mortillet, G. 1883. *Le Préhistorique. Origine et antiquité de l'homme* (1st ed.). Paris: C. Reinwald.
- Dennett, D. 1991. *Consciousness explained*. Boston: Little, Brown.
- d'Errico, F. 2001. Memories out of mind: The archaeology of the oldest memory systems. In A. Nowell (Ed.), *In the mind's eye: Multidisciplinary approaches*

- to the evolution of human cognition (pp. 33–49). Ann Arbor, MI: International Monographs in Prehistory.
- d'Errico, F., Henshilwood, C., & Nilssen, P. 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.
- Dobzhansky, T. 1944. On species and races of living and fossil man. *American Journal of Physical Anthropology*, 2, 251–265.
- Donald, M. 1991. *Origins of the modern mind: Three stages in the evolution of culture and cognition*. Cambridge, MA: Harvard University Press.
- Donald, M. 1993. Human cognitive evolution. What we were, what we are becoming. *Social Research*, 60, 143–170.
- Donald, M. 1998. Hominid enculturation and cognitive evolution. In C. Renfrew & C. Scarre (Eds.), *Cognition and material culture: The archaeology of symbolic storage* (pp. 7–17). Cambridge, UK: McDonald Institute Monographs.
- Donald, M. 1999. Preconditions for the evolution of protolanguage. In M. C. Corballis & S. E. G. Lea (Eds.), *The descent of mind: Psychological perspectives on hominid evolution* (pp. 138–154). Oxford: Oxford University Press.
- Dor, D. & Jablonka, E. 2004. Culture and genes in the evolution of human language. In N. Goren-Inbar & J. D. Speth (Eds.), *Human paleoecology in the Levantine Corridor* (pp. 105–115). Oxford: Oxbow Books.
- Dunbar, R. 2000. On the origin of the human mind. In P. Carruthers & A. Chamberlain (Eds.), *Evolution and the human mind: Modularity, language, and meta-cognition* (pp. 238–253). Cambridge, UK: Cambridge University Press.
- Eckblad, M. & Chapman, L. J. 1983. Magical ideation as an indicator of schizotypy. *Journal of Consulting and Clinical Psychology*, 5, 215–225.
- Edwards, S. W. 2001. A modern knapper's assessment of the technical skills of the Late Acheulean biface workers at Kalambo Falls. In J. D. Clark (Ed.), *Kalambo Falls prehistoric site* (pp. 605–611). Cambridge, UK: Cambridge University Press.
- Enard, W., Przeworski, M., Fisher, S. E., Lai, C. S. L., Wiebe, V., Kitano, T., Monaco, A. P., & Pääbo, S. 2002. Molecular evolution of FOXP2, a gene involved in speech and language. *Nature*, 418, 869–872.
- Ericsson, K. A. 2002. Attaining excellence through deliberate practice: Insights from the study of expert performance. In M. Ferrari (Ed.), *The pursuit of excellence through education* (pp. 21–56). Mahwah, NJ: Erlbaum.
- Ericsson, K. & Delaney, P. 1999. Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 257–297). Cambridge, UK: Cambridge University Press.
- Ericsson, K. A. & Lehmann, A. C. 1996. Expert and exceptional performance: Evidence on maximal adaptations on task constraints. *Annual Review of Psychology*, 47, 273–305.

- Eshed, V., Gopher, A., Galili, E., & Hershkovitz, I. 2004. Musculoskeletal stress markers in Natufian hunter-gatherers and Neolithic farmers in the Levant: The upper limb. *American Journal of Physical Anthropology*, 123, 303–315.
- Evans, P. D., Gilbert, S. L., Mekel-Bobrov, N., Vallender, E. J., Anderson, J. R., Vaez-Azizi, L. M., Tishkoff, S. A., Hudson, R. R., & Lahn, B. T. 2005. Microcephalin, a gene regulating brain size, continues to evolve adaptively in humans. *Science*, 309, 5741, 1717–1720.
- Falk, D. 2004. Prelinguistic evolution in early hominins: Whence motherese? *Behavioral and Brain Sciences*. Text distributed by BBS for peer commentary.
- Falk, D., Redmond, J. C. Jr., Guyer, J., Conroy, C., Recheis, W., Weber, G. W., & Seidler, H. 2000. Early hominid brain evolution: A new look at old endocasts. *Journal of Human Evolution*, 38, 695–717.
- Federmeier, K. D. & Kutas, M. 1999. Right words and left words: Electrophysiological evidence for hemispheric differences in meaning processing. *Cognitive Brain Research*, 8, 373–392.
- Fletcher, A. W. & Weghorst, J. A. 2005. Laterality of hand function in naturalistic chimpanzees. *Laterality*, 10, 219–242.
- Fletcher, P. C. & Henson, R. N. A. 2001. Frontal lobes and human memory. Insights from functional neuroimaging. *Brain*, 124, 849–881.
- Fodor, J. A. 1983. *The modularity of mind*. Cambridge, MA: The MIT Press.
- Fodor, J. 2000. *The mind doesn't work that way: The scope and limits of computational psychology*. Cambridge, MA: The MIT Press.
- Gabunia, L., Vekua, A., Lordkipanidze, D., Swisher, C. C., Ferring, R., Justus, A., Nioradze, M., Tvalcrelidze, M., Anton, S., Bosinski, G. C., Jöris, O., de Lumley, M.-A., Majusuradze, G. & Mouskhelishvili, A. 2000. Earliest Pleistocene hominid cranial remains from Dmanisi, Republic of Georgia: Taxonomy, geological setting and age. *Science*, 288, 1019–1025.
- Gamble, C. S. 1993. *Timewalkers. The prehistory of global colonization*. Stroud, Gloucestershire, UK: Sutton/Penguin.
- Gärdenfors, P. 2004. *How Homo became sapiens*. Oxford: Oxford University Press.
- Geneste, J.-M. 1991. Systèmes techniques de production lithique. Variations technico-économiques dans les processus de réalisation des outillages paléolithiques. *Techniques et Culture*, 17–18, 1–36.
- Gibbons, A. 2006. *The first human: The race to discover our earliest ancestors*. New York: Doubleday.
- Gibson, K. R. 1993. Part II. Introduction. Generative interplay between technical capacities, social relations, imitation and cognition. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognition in human evolution* (pp. 131–137). Cambridge, UK: Cambridge University Press.
- Gibson, K. R. & Ingold, T. (Eds.), 1993. *Tools, language and cognition in human evolution*. Cambridge, UK: Cambridge University Press.
- Gineste, M.-D. 1997. *Analogie et cognition*. Paris: Presses Universitaires de France.
- Goodall, J. 1986. *The chimpanzees of Gombe*. Cambridge, MA: Harvard University Press.

- Goren-Inbar, N. 1988. Notes on “decision making” by Lower and Middle Palaeolithic hominids. *Paléorient*, 14/2, 99–108.
- Goren-Inbar, N., Alpers, N., Kislev, M. E., Simchoni, O., Melamed, Y., Ben-Nun, A., & Werker, E. 2004. Evidence of hominid control of fire at Geshar Benat Ya’aqov, Israel. *Science*, 304, 725–727.
- Gould, S. J. & Vrba, E. 1982. Exaptation – a missing term in the science of form. *Paleobiology*, 8, 4–15.
- Gowlett, J. A. J. 1986. Culture and conceptualisation: The Oldowan-Acheulian gradient. In G. N. Bailey & P. Callow (Eds.), *Stone Age prehistory: Studies in memory of Charles McBurney* (pp. 243–260). Cambridge, UK: Cambridge University Press.
- Gowlett, J. A. J. 1992. Tools: The Palaeolithic record. In S. Jones, R. Martin, & D. Pilbeam (Eds.), *The Cambridge encyclopedia of human evolution* (pp. 350–360). Cambridge, UK: Cambridge University Press.
- Gowlett, J. A. J. & Hounsell, S. 2004. Clustering approaches to unravelling horizontal variation on an Acheulean site. *PaleoAnthropology*, 3, A50 (Abstracts of the PaleoAnthropology Society 2004 Meetings; Annual Meeting, March 30–31, 2004, Montreal).
- Graves, P. 1994. Flakes and ladders: What the archaeological record cannot tell us about the origins of language. *World Archaeology*, 26, 159–171.
- Grayson, D. K. & Delpech, F. 2002. Specialized Early Upper Palaeolithic hunters in southwestern France. *Journal of Archaeological Science*, 29, 1439–1449.
- Guiard, Y. 1987. Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model. *Journal of Motor Behavior*, 19, 486–517. Available at [http://cogprints.ecs.soton.ac.uk/archive/00000625/00/jmb\\_87.html](http://cogprints.ecs.soton.ac.uk/archive/00000625/00/jmb_87.html).
- Guilford, J. P. 1950. Creativity. *American Psychologist*, 5, 444–454.
- Guilford, J. P., Christensen, P. R., Merrifield, P. R., & Wilson, R. C. 1978. *Alternate uses: Manual of instruction and interpretation*. Orange, CA: Sheridan Psychological Services.
- Haidle, M. N. 1999. Der Unterschied liegt in der Zukunft: Untersuchungen zur Planungstiefe als Marker kognitiver Evolution. *Mitteilungen der Anthropologischen Gesellschaft in Wien*, 129, 1–11.
- Haidle, M. N. 2000. Neanderthals – ignorant relatives or thinking siblings? A discussion of the “cognitive revolution” at around 40,000 BP. In J. Orschiedt & G. C. Weniger (Eds.), *Neanderthals and modern humans: Discussing the transition. Central and Eastern Europe from 50.000–30.000 BP* (pp. 275–286). Mettmann: Neanderthal Museum.
- Haidle, M. N. 2004. Skillfull, but apish or on the way to becoming human? Object planning in the Lower Palaeolithic. In M. Toussaint, C. Draily, & J.-M. Cordy (Eds.), *Actes du XIV<sup>e</sup> Congrès UISPP. Section 4: Premiers hommes et Paléolithique inférieur, Sessions générales et posters* (pp. 69–73). Oxford: BAR International Series 1272.
- Haidle, M. N. 2006a. *Menschen – Denken – Objekte. Zur Problem-Lösung-Distanz als Kognitionsaspekt im Werkzeugverhalten von Tieren und im Laufe*

- der menschlichen Evolution*. PhD dissertation, Department of Geowissenschaft, Eberhard Karls Universität Tübingen.
- Haidle, M. N. 2006b. Ene, mene, muh – und schlaue bist Du? Zur Entwicklung des menschlichen Denkens. In G. Uelsberg & S. Lötters (Eds.), *Roots/Wurzeln der Menschheit* (pp. 199–208). Mainz: von Zabern.
- Haidle, M. N. 2007. *Archaeology*. In W. Henke & I. Tattersall (Eds.), *Handbook of palaeoanthropology*. Vol. 1: *Principles, methods, and approaches* (pp. 261–287). Heidelberg: Springer.
- Harris, L. J. 1991. Cerebral control for speech in right-handers and left-handers: An analysis of the views of Paul Broca, his contemporaries, and his successors. *Brain and Language*, 40, 1–50.
- Hauser, M., Chomsky, N., & Fitch, T. 2002. The faculty of language: What is it, who has it, and how did it evolve? *Science*, 298, 1569–1579.
- Hayden, B. 2003. *Shamans, sorcerers, and saints: A prehistory of religion*. Washington, DC: Smithsonian Institution Press.
- Hécaen, H. & de Ajuriaguerra, J. 1964. *Left-handedness: Manual superiority and cerebral dominance*. Transl. E. Ponder. New York: Grune & Stratton.
- Hellige, J. B. 1993. *Hemispheric asymmetry*. Cambridge, MA: Harvard University Press.
- Henshilwood, C. & Marean, C. 2003. The origin of modern human behavior. *Current Anthropology*, 44, 627–651.
- Henshilwood, C., d'Errico, F., Yates, R., Jacobs, Z., Tribolo, C., Duller, G. A., Mercier, N., Sealy, J. C., Valladas, H., Watts, I. & Wintle, A. G. 2002. Emergence of modern human behavior: Middle Stone Age engravings from South Africa. *Science*, 295, 1278–1280.
- Henshilwood, C., and B. Dubreuil. in press. Reading the artefacts: Gleaning language skills from the Middle Stone Age in southern Africa. In R. Botha (Ed.), *The Cradle of Language*. Stellenbosch, South Africa.
- Hepper, P. G., Wells, D. L., & Lynch, C. 2005. Prenatal thumb sucking is related to postnatal handedness. *Neuropsychologia*, 43, 313–315.
- Hewes, G. W. 1973. Primate communication and the gestural origin of language. *Current Anthropology*, 14, 5–24.
- Hinckley, K. 1996. *Haptic issues for virtual manipulation*. PhD dissertation, Department of Computer Science Department, University of Virginia.
- Hinckley, K., Pausch, R., Proffitt, D., Patten, J., & Kassell, N. 1997. Cooperative bimanual action. Paper presented at the ACM CHI'97 Conference on Human Factors in Computing Systems, March 22–27, 1997, Atlanta, Georgia.
- Holloway, R. L. 1995. Toward a synthetic theory of human brain evolution. In J.-P. Changeux & J. Chavaillon (Eds.), *Origins of the human brain* (pp. 42–54). Oxford: Clarendon Press.
- Howard-Jones, P. A., Blakemore, S. J., Samuel, E. A., Summers, I. R., & Claxton, G. 2005. Semantic divergence and creative story generation: An fMRI investigation. *Cognitive Brain Research*, 25, 240–250.
- Huffman, M. A. & Mohamedi, S. K. 1993. Tool-assisted predation on a squirrel by a female chimpanzee in the Mahale Mountains, Tanzania. *Primates*, 34.1, 93–98.

- Inizan, M.-L., Reduron-Ballinger, M., Roche, H. & Tixier, J. 1995. *Préhistoire de la pierre taillée. T. 4 Technologie de la pierre taillée*. Meudon: CREP.
- Inizan, M.-L., Reduron-Ballinger, M., Roche, H., & Tixier, J. 1999. *Préhistoire de la pierre taillée. T. 5 Technology and terminology of knapped stone followed by a multilingual vocabulary*. Nanterre: CREP.
- Jackendoff, R. 1999. Possible stages in the evolution of the language capacity. *Trends in Cognitive Science*, 3, 272–279.
- Jackendoff, R. 2002. *Foundations of language: Brain, meaning, grammar and evolution*. Oxford: Oxford University Press.
- Joulian, F. 1996. Comparing chimpanzee and early hominid techniques: Some contributions to cultural and cognitive questions. In P. Mellars & K. Gibson (Eds.), *Modelling the early human mind* (pp. 173–189). Cambridge, UK: McDonald Institute for Archaeological Research.
- Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., Reber, P. J., & Kounios, J. 2004. Neural activity when people solve verbal problems with insight. *PLoS Biology*, e97. Available at <http://biology.plosjournals.org/perlserv/?request=get-document&doi=10.1371>
- Kane, M. & Engle, R. 2002. The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin and Review*, 9, 637–671.
- Katz, R. 1982. *Boiling energy: Community healing among the Kalahari Kung*. Cambridge, MA: Harvard University Press.
- Keeley, L. H. 1977. The functions of Paleolithic flint tools. *Scientific American*, 237, 108–126.
- Kiefer, M., Weisbrod, M., Kern, I., Maier, S., & Spitzer, M. 1998. Right hemisphere activation during indirect semantic priming: Evidence from event-related potentials. *Brain and Language*, 64, 377–408.
- Kitahara-Frisch, J. 1993. The origin of secondary tools. In A. Berthelet & J. Chavallion (Eds.), *The use of tools by human and non-human primates* (pp. 239–246). A Fyssen Foundation Symposium. Oxford: Clarendon Press.
- Klein, R. G. 1995. Anatomy, behavior, and modern human origins. *Journal of World Prehistory*, 9, 167–198.
- Klein, R. G. 1999. *The human career*. Chicago: University of Chicago Press.
- Klein, R. G. & Edgar, B. 2002. *The dawn of human culture*. New York: Wiley.
- Köhler, W. 1925. *The mentality of apes*. New York: Harcourt, Brace.
- Kohn, M. & Mithen, S. 1999. Handaxes: Products of sexual selection? *Antiquity*, 73, 518–526.
- Kolk, H. 1995. A time-based approach to agrammatic production. *Brain and Language*, 50, 282–303.
- Kolk, H. 1998. *Disorders of syntax in aphasia*. In B. Stemmer & H. Whitaker (Eds.), *Handbook of neurolinguistics* (pp. 249–260). San Diego: Academic Press.
- Kortlandt, A. 1986. The use of stone tools by wild-living chimpanzees and earliest hominids. *Journal of Human Evolution*, 15, 77–132.

- Kyllonen, P. 1996. Is working memory capacity Spearman's *g*? In I. Dennis & P. Tapsfield (Eds.), *Human abilities: Their nature and measurement*. Mahwah, NJ: Erlbaum.
- Kyriacou, A. & Brugger, P. 2004. *How thinking determines language: The relativity of language relativity*. In G. Fulton, W. J. Sullivan, & A. R. Lommel (Eds.), *LACUS Forum XXX: Language, thought and reality* (pp. 159–165). Houston TX: LACUS.
- Lambert, P. 2006. La plasticité cérébrale. *Sciences Humaines*, 167, 52–53.
- Lambert, P. & Rezsöházy, R. 2004. *Comment les pattes viennent au serpent. Essai sur l'étonnante plasticité du vivant*. Paris: Flammarion (Nouvelle bibliothèque Scientifique).
- Langer, J. 1986. *The origins of logic. One to two years*. New York: Academic Press.
- Langer, J. 2000. The heterochronic evolution of primate cognitive development. In S. T. Parker, J. Langer, & M. L. McKinney (Eds.), *Biology, brains and behavior. The evolution of human development* (pp. 213–233). Santa Fe: School of American Research Press (Advanced Seminar Series).
- Lazar, S. W., Bush, G., Gollub, R. L., Fricchione, G. L., Khalsa, G., & Benson, H. 2000. Functional brain mapping of the relaxation response and meditation. *NeuroReport*, 11, 1581–1585.
- Lazar, S. W., Kerr, C. E., Wasserman, R. W., Gray, J. R., Greve, D. N., Treadway, M. T., McCarvey, M., Quinn, B. T., Duesk, J. A., Benson, H., Rauch, S. L., Moore, C. I., & Fischl, B. 2005. Meditation experience is associated with increased cortical thickness. *NeuroReport*, 16, 1893–1897.
- Le Ny, J.-J. 1997. Préface. In M.-D. Gineste. *Analogie et cognition* (pp. ix–xv). Paris: Presses Universitaires de France.
- Leonhard, D. & Brugger, P. 1998. Creative, paranormal, and delusional thought: A consequence of right hemisphere semantic activation? *Neuropsychiatry, Neuropsychology and Behavioral Neurology*, 11, 177–183.
- Leroi-Gourhan, A. 1943. *Évolution et techniques. Tome I. L'homme et la matière*. Paris: Albin Michel.
- Leroi-Gourhan, A. 1945. *Évolution et techniques. Tome II. Milieu et techniques*. Paris: Albin Michel.
- Leroi-Gourhan, A. 1964. *Le geste et la parole. Tome I. Technique et langage*. Paris: Albin Michel.
- Leroi-Gourhan, A. 1965. *Le geste et la parole. Tome II. La mémoire et les rythmes*. Paris: Albin Michel.
- Leroi-Gourhan, A. 1993. *Gesture and speech*. Cambridge, MA: The MIT Press.
- Lewis-Williams, D. 2002. *The mind in the cave*. London: Thames & Hudson.
- Liolios, D. 2003. L'apparition de l'industrie osseuse au début du Paléolithique supérieur. Un transfert de techniques de travail du végétal sur les matières osseuses. In R. Desbrosse & A. Thévenin (Dir.), *Préhistoire de l'Europe. Des origines à l'Âge du Bronze* (pp. 219–225). Actes des 125<sup>e</sup> Congrès nationaux des sociétés historiques et scientifiques (Lille, 2000). Paris: Éditions du Comité des Travaux Historiques et Scientifiques.

- Lock, A. 2004. *Course outline*. Palmerston North, New Zealand: Massey University.
- Longo, L. & Skakun, N. (Eds.). 2008. "Prehistoric Technology" 40 years later: *Functional studies and the Russian legacy*. Oxford: Archaeopress, BAR International Series 1783.
- Ludwig, B. V. & Harris, J. W. K. 1994. Handedness and knapping skill: Their effects on Plio-Pleistocene lithic assemblage variability. In *The Neogene & Quaternary. Pre-circulated papers of the 3rd World Archaeological Congress, New Delhi, 4–11 Dec 1994*. New Delhi: World Archaeological Congress.
- Lutz, A., Greischar, L. L., Rawlings, N. B., Ricard, M., & Davidson, R. J. 2004. Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. *Proceedings of the National Academy of Sciences*, 101, 16, 369–16, 373.
- Mackay, C. E., Barrick, T. R., Roberts, N., DeLisi, L. E., Maes, F., Vandermeulen, D., & Crow, T. J. 2003. Application of a new image analysis technique to the study of brain asymmetry in schizophrenia. *Psychiatry Research: NeuroImaging*, 124, 25–35.
- Majno, G. 1975. *The healing hand: Man and wound in the ancient world*. Cambridge, UK: Cambridge University Press.
- Malafouris, L. 2004. The cognitive basis of material engagement: Where brain, body and culture conflate. In E. DeMarrais, C. Gosden, & C. Renfrew (Eds.), *Rethinking materiality: The engagement of mind with the material world* (pp. 53–61). Cambridge, UK: McDonald Institute Monographs. Available at <http://cogprints.org/4629/>.
- Man, J. 2002. *Gutenberg: How one man remade the world with words*. New York: Wiley.
- Mania, D. 1995. The utilisation of large mammal bones in Bilzingsleben: A special variant of Middle Pleistocene man's relationship to his environment. In H. Ullrich (Ed.), *Man and environment in the Palaeolithic* (pp. 239–246). Colloque international de Liège, Liège: Études et Recherches Archéologiques de l'Université de Liège 62.
- Marchant, F. & McGrew, W. C. 2005. Percussive technology: Chimpanzee baobab smashing and the evolutionary modeling of hominid knapping. In V. Roux & B. Brill (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 341–350). Cambridge, UK: McDonald Institute for Archaeological Research.
- Marshack, A. 1985. Theoretical concepts that lead to new analytic methods, modes of enquiry and classes of data. *Rock Art Research*, 2, 95–111.
- Marshack, A. 1991. The Tai plaque and calendrical notation in the Upper Palaeolithic. *Cambridge Archaeological Journal*, 1, 25–61.
- Martin, R. D. 1998. Comparative aspects of brain evolution: Scaling, energy costs and confounding variables. In N. G. Jablonski & L. C. Aiello (Eds.), *The origin and diversification of language* (pp. 35–68). San Francisco: California Academy of Sciences (Scientific Publications Anthropology and Archaeology).
- Mayr, E. 1950. Taxonomic categories in fossil hominids. *Cold Spring Harbor Symposium on Quantitative Biology*, 15, 109–118.

- McBrearty, S. & Brooks, A. 2000. The revolution that wasn't: A new interpretation of the origin of modern human behavior. *Journal of Human Evolution*, 39, 453–563.
- McClenon, J. 1997. Shamanic healing, human evolution and the origin of religion. *Journal for the Scientific Study of Religion*, 36, 345–354.
- McClenon, J. 2002. *Wondrous healing: Shamanism, human evolution and the origin of religion*. DeKalb: Northern Illinois University Press.
- McCrae, R. R. 1987. Creativity, divergent thinking, and openness to experience. *Journal of Personality and Social Psychology*, 52, 1258–1265.
- McDougall, I., Brown, F. H., & Fleagle, J. G. 2005. Stratigraphic placement and age of modern humans from Kibish, Ethiopia. *Nature*, 433, 733–736.
- McGrew, W. C. 1993. The intelligent use of tools: Twenty propositions. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognition in human evolution* (pp. 151–170). Cambridge, UK: Cambridge University Press.
- McGrew, W. C. & Marchant, L. F. 1992. Chimpanzees, tools, and termites: Hand preference or handedness? *Current Anthropology*, 33, 114–119.
- McGrew, W. C. & Marchant, L. F. 1997. On the other hand: Current issues in and meta-analysis of the behavioral laterality of hand function in nonhuman primates. *Yearbook of Physical Anthropology*, 40, 201–232.
- McNabb, J. 1989. Sticks and stones: A possible experimental solution to the question of how the Clacton spear-point was made. *Proceedings of the Prehistoric Society*, 55, 251–271.
- McPherron, S. P. 1999. Ovate and pointed handaxe assemblages: Two points make a line. *Préhistoire Européenne*, 14, 9–32.
- McPherron, S. P. 2000. Handaxes as a measure of the mental capabilities of early hominids. *Journal of Archaeological Science*, 27, 655–663.
- Mednick, S. A. 1962. The associative basis of the creative process. *Psychological Review*, 220–232.
- Mellars, P. 1996. *The Neanderthal legacy: An archaeological perspective from Western Europe*. Princeton, NJ: Princeton University Press.
- Mellars, P. 2002. Archaeology and the origins of modern humans: European and African perspectives. In T. J. Crow (Ed.), *The speciation of modern Homo sapiens* (pp. 32–34). Oxford: Oxford University Press.
- Mercader, J., Barton, H., Gillespie, J., Harris, J., Kuhn, S., Tyler, R., & Boesch, C. 2007. 4,300-year-old chimpanzee sites and the origins of percussive stone technology. *Proceedings of the National Academy of Sciences*, 104, 3043–3048.
- Mercader, J., Panger, M., & Boesch, C. 2002. Excavation of a chimpanzee stone tool site in the African rainforest. *Science*, 296, 1452–1455.
- Minichillo, T. J. 2006. Raw material use and behavioral modernity: Howiesons Poort lithic foraging strategies. *Journal of Human Evolution*, 50, 359–364.
- Minkel, J. R. 2006. Offerings to a stone snake provide the earliest evidence of religion. *Scientific American* online last accessed 5/21/07: <http://www.sciam.com/article.cfm?articleID=3FE89A86-E7F2-99DF-366D045A5BF3EAB1>
- Mithen, S. 1996. *The prehistory of the mind*. London: Thames & Hudson.

- Mohr, C., Krummenacher, P., Landis, T., Sandor, P., Fathi, M., & Brugger, P. 2005. Psychometric schizotypy modulates levodopa effects on lateralized lexical decision performance. *Journal of Psychiatric Research*, 39, 241–250.
- Monnier, J. L., Hallégouët, B., Hinguant, S., Laurent, M., Auguste, P., Bahain, J.-J., Falguères, C., Geebhardt, A., Marguerie, D., Molines, N., Morzadec, H., & Yokoama, Y. 1994. A new regional group of the Lower Paleolithic in Brittany (France), recently dated by electron spin resonance. *Comptes rendus de l'Académie des Sciences*, 319, 155–160.
- Montagu, A. 1976. Toolmaking, hunting, and the origin of language. In H. D. Steklis, S. Harnad, & J. Lancaster (Eds.), *Origins and evolution of language and speech* (pp. 266–274). New York: Annals of the New York Academy of Sciences.
- Moore, A. M. T., Hillman, G. C., & Legge, A. J. 2000. *Village on the Euphrates: From foraging to farming at Abu Hureyra*. Oxford: Oxford University Press.
- Morgan, A. H. 1973. The heritability of hypnotic susceptibility in twins. *Journal of Abnormal and Social Psychology*, 82, 55–61.
- Mosquera, M., Llorente, M., Riba, D., Estebanz, F., González-Brao, M., Lorenzo, C., Sanmartí, N., Toll, M., Carbonell, E., & Feliu, O. 2007. Ethological study of manual laterality in naturalistic housed chimpanzees (*Pan troglodytes*) from the Mona Foundation sanctuary (Girona, Spain). *Laterality*, 12, 19–30.
- Narr, K. L., Bilder, R. M., Luders, E., Thompson, P. M., Woods, R. P., Robinson, D., Szeszko, P. R., Dimtcheva, T., Gurbani, M., & Toga, A. W. 2007. Asymmetries of cortical shape: Effects of handedness, sex and schizophrenia. *Neuroimage*, 34, 939–948.
- Newberg, A., Alavi, A., Baime, M., Pourdehnad, M., Santanna, J., & d'Aquili, E. 2001. The measurement of regional cerebral blood flow during the complex cognitive task of meditation: A preliminary SPECT study. *Psychiatry Research: Neuroimaging Section*, 106, 113–122.
- Noble, W. & Davidson, I. 1996. *Human evolution, language and mind. A psychological and archaeological inquiry*. Cambridge, UK: Cambridge University Press.
- Nolfi, S. 1997. Using emergent modularity to develop control systems for mobile robots. *Adaptive Behavior*, 5, 343–364.
- Oakley, K. P., Andrews, P., Keeley, L. H., & Clark, J. D. 1977. A reappraisal of the Clacton spearpoint. *Proceedings of the Prehistoric Society*, 43, 13–30.
- Ochse, R. 1990. *Before the gates of excellence: The determinants of creative genius*. New York: Cambridge University Press.
- Ohnuma, K., Aoki, K., & Akazawa, T. 1997. Transmission of tool-making through verbal and non-verbal communication. Preliminary experiments in Levallois flake production. *Anthropological Science*, 105, 159–168.
- Oldfield, R. C. 1971. The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9, 97–113.
- Oller, D. K. 2007. Natural logic of vocal capabilities and the evolution of language. Paper presented at the ILA conference, March 29–April 1, 2007, Hunter College, New York.
- Oppenheimer, S. 2004. *Out of Africa's eden*. Johannesburg: Jonathan Ball.

- Oswalt, W. 1976. *An anthropological analysis of food-getting technology*. New York: Wiley.
- Papademetriou, E., Sheu, C.-F., & Michel, G. F. 2005. A meta-analysis of primate hand preferences, particularly for reaching. *Journal of Comparative Psychology*, 119, 33–48.
- Parker, S. T. & Milbrath, C. 1993. Higher intelligence, propositional language, and culture as adaptations for planning. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognition in human evolution* (pp. 314–333). Cambridge, UK: Cambridge University Press.
- Patterson, L. W. & Sollberger, J. B. 1986. Comments on Toth's right-handedness study. *Lithic Technology*, 15, 109–111.
- Pearce, T. M. 2005. Did they talk their way out of Africa? Commentary on Corballis, M. C. 2005. From mouth to hand: Gesture, speech, and the evolution of right-handedness. *Behavioral & Brain Sciences*, 26, 235–236, 250–260.
- Pelegrin, J. 1985. Réflexions sur le comportement technique. In M. Otte (Ed.), *La signification culturelle des industries lithiques* (pp. 72–88). Oxford: BAR International Series 239.
- Pelegrin, J. 1990. Prehistoric lithic technology: Some aspects of research. *Archaeological Review from Cambridge*, 9, 116–125.
- Pelegrin, J. 1993. A framework for analysing prehistoric stone tools manufacture and a tentative application to some early lithic industries. In A. Berthelet & Chavaillon J. (Eds.), *The use of tools by human and non-human primates: A symposium of the Fyssen foundation* (pp. 302–314). Oxford: Clarendon Press.
- Pelegrin, J. 1995. *Technologie lithique. Le Châtelperronien de Roc-de-Combe (Lot) et de la Côte (Dordogne)*. Paris: CNRS Éditions (Cahiers du Quatenaire 20).
- Pelegrin, J. 2000. Les techniques de débitage laminaire au Tardiglaciaire. Critères de diagnose et quelques réflexions. In B. Valentin, P. Bodu, & M. Christensen (Eds.), *L'Europe Centrale et Septentrionale au Tardiglaciaire. Confrontation des modèles régionaux* (pp. 73–86). Nemours: Mémoires du Musée de Préhistoire d'Île-de-France 7.
- Pelegrin, J. 2004. Le milieu intérieur d'André Leroi-Gourhan et l'analyse de la taille de pierre au Paléolithique. In F. Audouze & N. Schlanger (Dirs.), *Autour de l'homme. Contexte et actualité d'André Leroi-Gourhan* (pp. 149–162). Antibes: Éditions APDCA.
- Pelegrin, J. 2005. Remarks about archaeological techniques and methods of knapping: Elements of a cognitive approach to stone knapping. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 23–33). Cambridge, UK: McDonald Institute for Archaeological Research.
- Pelegrin, J., Karlin, C., & Bodu, P. 1988. "Chaînes opératoires". Un outil pour le préhistorien. In J. Tixier (Ed.), *Technologie préhistorique* (pp. 55–62). Paris: CNRS Éditions (Notes et monographies techniques 25).
- Perlès, C. 1991. Économie des matières premières et économie du débitage. Deux conceptions opposées. In *25 ans d'études technologiques en Préhistoire* (pp. 35–45).

- XI<sup>e</sup> Rencontres internationales d'archéologie et d'histoire d'Antibes. Juan les Pins: Éditions APDCA.
- Perpère, M. 1999. Le débitage Levallois d'Ault (Somme, France). *L'Anthropologie (Paris)*, 103, 343–376.
- Petraglia, M. D., Shipton, C., & Paddayya, K. 2005. Life and mind in the Acheulean: A case study from India. In C. Gamble & M. Porr (Eds.), *The hominid individual in context. Archaeological excavations of Lower and Middle Palaeolithic landscapes, locales and artifacts* (pp. 197–219, 271–309). London: Routledge.
- Phillipson, L. 1997. Edge modification as an indicator of function and handedness of Acheulean handaxes from Kariandusi, Kenya. *Lithic Technology*, 22, 171–183.
- Piaget, J. 1967. *Biologie et Connaissance. Essai sur les relations entre les régulations organiques et les processus cognitifs*. Paris: Gallimard.
- Pigeot, N. 1987. *Magdaléniens d'Étiolles. Économie de débitage et organisation sociale*. Paris: CNRS Éditions (XXV<sup>e</sup> supplément à *Gallia Préhistoire*).
- Pigeot, N. 1991. Réflexions sur l'histoire technique de l'homme. De l'évolution cognitive à l'évolution culturelle. *Paléo*, 3, 167–200.
- Pinker, S. 1997. *How the mind works*. New York: W. W. Norton.
- Pitti, C. & Radmilli, A. M. 1984. La stazione del Paleolitico a Castel di Guido. *Atti della xxiv Riunione Scientifica*. (pp. 73–87). Firenze: Pubblicazione dell'Istituto italiano di Preistoria e Protohistoria.
- Pizzagalli, D., Lehmann, D., & Brugger, P. 2001. Lateralized direct and indirect semantic priming effects in subjects with paranormal experiences and beliefs. *Psychopathology*, 34, 75–80.
- Pobiner, B. L. 1999. The use of stone tools to determine handedness in hominids. *Current Anthropology*, 40, 90–92.
- Pope, M. 2004. Behavioural implications of biface discard: Assemblage variability and land-use at the Middle Pleistocene site of Boxgrove. In E. A. Walker, F. F. Wenban-Smith, & F. Healy (Eds.), *Lithics in action* (pp. 38–47). Papers from the Lithic Studies in the Year 2000 Conference. Oxford: Oxbow Books (Lithic Studies Society Occasional Paper 8).
- Pope, M. & Roberts, M. B. 2005. Observations on the relationship between Palaeolithic individuals and artefact scatters at the Middle Pleistocene site of Boxgrove, UK. In C. Gamble & M. Porr (Eds.), *The hominid individual in context. Archaeological excavations of Lower and Middle Palaeolithic landscapes, locales and artifacts* (pp. 81–97, 271–309). London: Routledge.
- Porac, C. & Coren, S. 1981. *Lateral preferences and human behavior*. New York: Springer.
- Posnansky, M. 1959. Some functional considerations on the handaxe. *Man*, 59, 42–44.
- Premack, D. & Woodruff, G. 1978. Chimpanzee problem-solving: A test for comprehension. *Science*, 202, 532–535.
- Pruetz, J. D. & Bertolani, P. 2007. Savanna chimpanzees, *Pan troglodytes* verus, hunt with tools. *Current Biology*, 17, 412–417.
- Rabardel, P. 1995. *Les Hommes et les technologies. Approche cognitive des instruments contemporains*. Paris: Armand Colin.

- Ramachandran, V. S. 1995. Anosognosia in parietal lobe syndrome. *Consciousness and Cognition*, 4, 22–51.
- Reinhart, T. 2002. The theta system: An overview. *Theoretical Linguistics*, 28, 229–290.
- Reinhart, T. & Siloni, T. 2005. The lexicon-syntax parameter: Reflexivization and other arity operations. *Linguistic Inquiry*, 389–436.
- Renfrew, C. & Scarre, C. 1998. *Cognition and material culture: The archaeology of symbolic storage*. Cambridge, UK: McDonald Institute for Archaeological Research.
- Ritchey, T. 2008. General morphological analysis. A general method for non-quantified modeling. Available at <http://www.swemorph.com/ma.html>.
- Roberts, M. B. & Parfitt, S. A. 1999. *Boxgrove: A Middle Pleistocene hominid site at Eartham Quarry, Boxgrove, West Sussex. Vol. 1*. London: English Heritage (Archaeological Report 17).
- Roberts, M. B., Parfitt, S. A., Pope, M. I., Wenban-Smith, F. F., Macphail, R. I., Locker, A., & Stewart, J. R. 1997. Boxgrove, West Sussex: Rescue excavations of a Lower Palaeolithic landsurface (Boxgrove Project B, 1989–91). *Proceedings of the Prehistoric Society*, 63, 303–358.
- Roche, H. 1980. *Premiers outils taillés d'Afrique*. Paris: Société d'ethnographie (Publications du Laboratoire d'ethnologie et de sociologie comparative, Université de Paris X, coll. Afrique ancienne 1).
- Roche, H. 1989. Technological evolution in early hominids. *OSSA*, 14, 97–98.
- Roche, H. 2005. From simple flaking to shaping: Stone-knapping evolution among early hominins. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 35–48). Cambridge, UK: McDonald Institute for Archaeological Research.
- Roche, H. & Texier, P.-J. 1996. Evaluation of technical competence of *Homo erectus* in east Africa during the Middle Pleistocene. In J. R. F. Bower & S. Sartono (Eds.), *Proceedings of the Pithecanthropus Centennial, 1893–1993; vol. I. Palaeoanthropology: Evolution and ecology of Homo erectus* (pp. 153–167). Leiden: Pithecanthropus Centennial Foundation.
- Roche, H., Delagnes, A., Brugal, J.-P., Feibel, C., Kibunija, M., Mourre, V., & Texier, P.-J. 1999. Early hominid stone tool production and technical skill 2.34 Myr ago in West Turkana, Kenya. *Nature*, 399, 57–60.
- Rodel, M., Cook, N. D., Regard, M., & Landis, T. 1992. Hemispheric dissociation in judging semantic relations: Complementarity for close and distant associates. *Brain and Language*, 43, 448–459.
- Roe, D. A. 1968. British Lower and Middle Palaeolithic handaxe groups. *Proceedings of the Prehistoric Society*, 34, 1–82.
- Rossano, M. J. 2003. Expertise and the evolution of consciousness. *Cognition*, 89, 207–236.
- Rossano, M. J. 2007a. Supernaturalizing social life: Religion and the evolution of human cooperation. *Human Nature*, 18, 272–294.
- Rossano, M. J. 2007b. Did meditating make us human? *Cambridge Archaeological Journal*, 17, 47–58.

- Roux, V. & Bril, B. (Eds.). 2005a. *Stone knapping: The necessary conditions for a uniquely hominin behaviour*. Cambridge, UK: McDonald Institute for Archaeological Research.
- Roux, V. & Bril, B. 2005b. General introduction: A dynamic systems framework for studying a uniquely hominin innovation. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 1–18). Cambridge, UK: McDonald Institute for Archaeological Research.
- Roux, V. & David, E. 2005. Planning abilities as a dynamic perceptual-motor skill: An actualist study of different levels of expertise involved in stone knapping. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 91–108). Cambridge, UK: McDonald Institute for Archaeological Research.
- Ruff, C. B., Trinkaus, E., & Holliday, T. W. 1997. Body mass and encephalization in Pleistocene *Homo*. *Nature*, 387, 173–176.
- Rugg, G. & Mullane, M. 2001. Inferring handedness from lithic evidence. *Laterality*, 6, 247–259.
- Rust, A. 1973–1974. Handwerkliches Können und Lebensweise des Steinzeitmenschen. *Mannheimer Forum*, 2, 193–247.
- Saban, R. 1995. Image of the human fossil brain: Endocranial cast and meningeal vessels in young and adult subjects. In J.-P. Changeux & J. Chavillon (Eds.), *Origins of the human brain* (pp. 11–39). Oxford: Clarendon Press.
- Samuels, R. 2000. Massively modular minds: Evolutionary psychology and cognitive architecture. In P. Carruthers & A. Chamberlain (Eds.), *Evolution and the human mind. Modularity, language and meta-cognition* (pp. 13–46). Cambridge, UK: Cambridge University Press.
- Sarringhaus, L. A., McGrew, W. C., & Marchant, L. F. 2005. Misuse of anecdotes in primatology: Lessons from citation analysis. *American Journal of Primatology*, 65, 283–288.
- Schick, K. D. 1994. The Movius line reconsidered: Perspectives on the earlier Palaeolithic of Eastern Asia. In R. S. Corruccini & R. L. Ciochon (Eds.), *Integrative paths to the past: Palaeoanthropological advances in honor of F. Clark Howell* (pp. 569–595). Englewood Cliffs, NJ: Prentice-Hall.
- Schick, K. D. & Toth, N. 1993. *Making silent stones speak: Human evolution and the dawn of technology*. New York: Simon & Schuster.
- Schick, K. D., Toth, N., & Garufi, G. 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, N. 2004. “Suivre les gestes, éclat par éclat”. La chaîne opératoire d’André Leroi-Gourhan. In F. Audouze & N. Schlanger (Dirs.), *Autour de l’homme. Contexte et actualité d’André Leroi-Gourhan* (pp. 127–147). Antibes: Éditions APDCA.
- Schlanger, N. 2005. The chaîne opératoire. In C. Renfrew & P. Bahn (Dirs.), *Archaeology: The key concepts* (pp. 25–31). Abingdon: Routledge.
- Segal, M. 2001. *Creativity and personality type. Tools for understanding and inspiring the many voices of creativity*. Huntington Beach, CA: Telos Publications.

- Semaw, S. 2000. The world's oldest stone artefacts from Gona, Ethiopia: Their implications for understanding stone technology and patterns of human evolution between 2.6–1.5 million years ago. *Journal of Archaeological Science*, 27, 1197–1214.
- Semaw, S., Renne, P., Harris, J. W. K., Feibel, C. S., Bernor, R. L., Fesseha, N., & Mowbray, K. 1997. 2.5-million-year-old stone tools from Gona, Ethiopia. *Nature*, 385, 333–336.
- Semenov, S. A. 1964. *Prehistoric technology*. Transl. M. W. Thompson. London: Cory, Adams & Mackay (1st ed. 1957).
- Séris, J.-P. 1994. *La technique*. Paris: Presses Universitaires de France (coll. Les grandes questions de la philosophie).
- Sigaut, F. 1991. Un couteau ne sert pas à couper mais en coupant. Structure, fonctionnement et fonction dans l'analyse des objets. In *25 ans d'études technologiques en Préhistoire* (pp. 21–34). XI<sup>e</sup> Rencontres internationales d'archéologie et d'histoire d'Antibes. Juan les Pins: Éditions APDCA.
- Sigerist, H. 1987. *A history of medicine* (vols. 1, 2). Oxford, UK: Oxford University Press.
- Simondon, G. 1958. *Du mode d'existence des objets techniques*. Paris: Aubier.
- Slioussar, N. 2007. *Grammar and information structure: A study with reference to Russian*. Utrecht: LOT Dissertation Series.
- Soffer, O. 1989. Storage, sedentism and the Eurasian Palaeolithic record. *Antiquity*, 63, 719–732.
- Soressi, M. & Geneste, J.-M. 2006. Discussing the history and the efficacy of the chaîne opératoire approach to lithic analysis, core reduction, chaîne opératoire, and other methods: The epistemologies of different approaches to lithic analysis. In *Electronic Symposium "Core reduction, Chaîne opératoire, and other methods: The epistemologies of different approaches to lithic analysis"*, 71st Annual Meeting of the Society for American Archaeology, San Juan, Puerto Rico (<http://www.saa.org/meetings/symposium/197/>).
- Stadler, M. A. & Frensch, P. A. (Eds.). 1998. *Handbook of implicit learning*. Thousand Oaks, CA: Sage.
- Steele, J., Quinlan, A., & Wenban-Smith, F. F. 1995. Stone tools and the linguistic capabilities of earlier hominids. *Cambridge Archaeological Journal*, 5, 245–256.
- Steele, J. & Uomini, N. T. 2005. Humans, tools and handedness. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 217–239). Cambridge, UK: McDonald Institute for Archaeological Research.
- Steele, J. & Uomini, N. 2009. Can the archaeology of manual specialization tell us anything about language evolution? A survey of the state of play. *Cambridge Archaeological Journal* 19, 1, 97–110.
- Stiner, M. C. 2006. Middle Paleolithic subsistence ecology in the Mediterranean region. In E. Hovers & S. L. Kuhn (Eds.), *Transitions before the transition* (pp. 213–231). New York: Springer.
- Stout, D. 2003. *Stone tools and the evolution of human thinking: Cultural, biological and archaeological elements in an anthropology of human origins*. PhD dissertation, Department of Archaeology, Indiana University.

- Stout, D. 2005. The social and cultural context of stone-knapping skill acquisition. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 331–340). Cambridge, UK: McDonald Institute for Archaeological Research.
- Stout, D., Toth, N., & Schick, K. 2000. Stone tool-making and brain activation: Position emission tomography (PET) studies. *Journal of Archaeological Science*, 27, 1215–1223.
- Stowe, L. A., Paans, A. M. J., Wijers, A. A., Mulder, G., Koster, J., & Vaalburg, W. 1998. Semantic ambiguity activates right frontal cortex. *NeuroImage*, 7, S189.
- Straus, L. G. 1996. The archaeology of the Pleistocene-Holocene transition in southwest Europe. In L. G. Straus, B. V. Eriksen, J. Erlandson, & D. Yesner (Eds.), *Humans at the end of the Ice Age: The archaeology in the Pleistocene-Holocene transition* (pp. 83–99). New York: Plenum Press.
- Stringer, C. & Andrews, P. 2005. *The complete world of human evolution*. London: Thames & Hudson.
- Suddendorf, T. 1999. The rise of metamind. In M. C. Corballis & S. E. G. Lea (Eds.), *The descent of mind: Psychological perspectives on hominid evolution* (pp. 218–260). Oxford: Oxford University Press.
- Takeoka, T. 1991. Développement de la latéralité examinée à partir de l'analyse de la pierre taillée du Paléolithique. *Journal of the Anthropological Society of Nippon*, 99, 497–516.
- Tattersall, I. 1995. *The fossil trail: How we know what we think we know about human evolution*. New York: Oxford University Press.
- Tattersall, I. 2000. Once we were not alone. *Scientific American*, 282, 56–62.
- Tattersall, I. 2004. What happened in the origin of human consciousness? *The Anatomical Record (The New Anatomist)*, 267B, 19–26.
- Thieme, H. 1997. Lower Paleolithic hunting spears from Germany. *Nature*, 385, 807–810.
- Thieme, H. 1999. Altpaläolithische Holzgeräte aus Schöningen, Lkr. Helmstedt. *Germania*, 77, 451–487.
- Thieme, H. & Veil, S. 1985. *Neue Untersuchungen zum eemzeitlichen Elefantenjagdplatz Lehringen, Ldkr. Verden. Die Kunde*, N.F. 36, 11–58.
- Tixier, J. 1967. Procédés d'analyse et questions de terminologie concernant l'étude des ensembles industriels du Paléolithique récent et de l'Épipaléolithique dans l'Afrique du Nord-Ouest. In W. W. Bishop & J. Desmond-Clark (Eds.), *Background to evolution in Africa. Proceedings of a symposium held at Burg Wartenstein Austria, July–August 1965* (pp. 771–820). Chicago: University of Chicago Press.
- Tixier J., Inizan M.-L., & Roche, H. 1980. *Préhistoire de la pierre taillée*. T. 1 *Terminologie et technologie*. Valbonne: CREP.
- Torrance, E. P. 1966. *The Torrance tests of creative thinking: Norms – technical manual*. Lexington, MA: Personal Press.
- Toth, N. P. 1982. *The stone technologies of early hominids at Koobi Fora, Kenya: An experimental approach*. PhD dissertation, Department of Anthropology, University of California.

- Toth, N. 1985a. The Oldowan reassessed: A close look at early stone artifacts. *Journal of Archaeological Science*, 12, 101–120.
- Toth, N. 1985b. Archaeological evidence for preferential right-handedness in the Lower and Middle Pleistocene, and its possible implications. *Journal of Human Evolution*, 14, 607–614.
- Toth, N. 1993. Early stone industries and inferences regarding language and cognition. In K. R. Gibson & T. Ingold (Eds.), *Tool, language and cognition in human evolution* (pp. 346–362). Cambridge, UK: Cambridge University Press.
- Toth, N., Schick, K. D., Savage-Rumbaugh, S., Sevcik, R. A., & Rumbaugh, D. M. 1993. Pan the toolmaker: Investigations into stone tool-making and tool-using capabilities of a bonobo (*Pan paniscus*). *Journal of Archaeological Science*, 20, 81–91.
- Trinkaus, E. 1983. *The Shanidar Neanderthals*. New York: Academic Press.
- Uomini, N. T. 2001. *Lithic indicators of handedness: Assessment of methodologies and the evolution of laterality in hominids*. Unpublished Master's thesis, Department of Anthropology, University of Durham.
- Uomini, N. T. 2005. *A study of interindividual variation in bimanual knapping configurations, and the effects of handedness on knapping products*. Technical report of experiments undertaken July 2005, Lejre Historical-Archaeological Research Centre, Lejre, Denmark.
- Uomini, N. T. 2007. *In the knapper's hands: Testing markers of laterality in hominin lithic production, with reference to the common substrate of language and handedness*. PhD dissertation, Department of Archaeology, University of Southampton.
- Uomini, N. T. (in press). Handedness in Neanderthals. In N. J. Conard & J. Richter (Eds.), *Neanderthal lifeways, subsistence and technology*. Heidelberg: Springer.
- Vargha-Khadem, F., Watkins, K., Alcock, K., Fletcher, P., & Passingham, R. 1995. Pragmatic and nonverbal cognitive deficits in a large family with a genetically transmitted speech and language disorder. *Proceedings of the National Academy of Sciences*, 92, 930–933.
- Vargha-Khadem, F., Watkins, K. E., Price, C. J., Ashburner, J., Alcock, K. J., Connelly, A., Frackowiak, R. S. J., Friston, K. J., Pembrey, M. E., Mishkin, M., Gadian, D. G., & Passingham, R. 1998. Neural basis of an inherited speech and language disorder. *Proceedings of the National Academy of Sciences*, 95, 12,695–12,700.
- Vauclair, J. 1992. *L'intelligence de l'animal*. Paris: Éditions du Seuil (Science ouverte).
- Veil, S. 1991. Die Nachbildung der Lanze von Lehringen. Experimente zur Holzbearbeitung im Mittelpaläolithikum. *Die Kunde*, N.F. 41/42, 9–22.
- Walker, A. & Leakey, R. E. F. (Eds.). 1993. *The Nariokotome Homo erectus skeleton*. Cambridge, MA: Harvard University Press.
- Walker, M. J., Rodríguez Estrella, T., Carrión García, J. S., Mancheño Jiménez, M.-A., Schwenninger, J.-L., López Martínez, M., López Jiménez, A., San Nicolás

- del Toro, M., Hills, M. D., & Walkling, T. 2006. Cueva Negra del Estrecho del Río Quípar (Murcia, southeast Spain): An Acheulian and Levallois-Mousteroid assemblage of Paleolithic artifacts excavated in a Middle Pleistocene faunal context with hominin skeletal remains. *Journal of Eurasian Prehistory*, 4, 3–43.
- Wallace, R. K., Benson, H., & Wilson, A. F. 1971. A wakeful hypometabolic physiological state. *American Journal of Physiology*, 221, 795–799.
- Weaver, A. 2002. Relative cerebellar and cerebral hemisphere volume in Pliocene and Pleistocene *Homo*: A complex trajectory. *Journal of Human Evolution*, 42, A38.
- Weinstein, S. & Graves, R. E. 2001. Creativity, schizotypy, and laterality. *Cognitive Neuropsychiatry*, 6, 131–146.
- West, T. G. 1997. *In the mind's eye*. New York: Prometheus Books.
- White, J. P. & Thomas, D. H. 1972. What mean these stones? Ethno-taxonomic models and archaeological interpretations in the New Guinea highlands. In D. L. Clarke (Ed.), *Models in archaeology* (pp. 275–308). London: Methuen.
- White, M. J. 1998a. Twisted ovate bifaces in the British Lower Palaeolithic: Some observations and implications. In N. Ashton, F. Healy, & P. Pettitt (Eds.), *Stone Age archaeology: Essays in honour of John Wymer* (pp. 98–104). Oxford: Oxbow Books (Lithic Studies Society Occasional Paper 6).
- White, M. J. 1998b. On the significance of Acheulean biface variability in southern Britain. *Proceedings of the Prehistoric Society*, 64, 15–44.
- White, T. D., Asfaw, B., DeGusta, D., Gilbert, H., Richards, G. D., Suwa, G., & Howell, F. C. 2003. Pleistocene *Homo sapiens* from Middle Awash, Ethiopia. *Nature*, 423, 742–747.
- White, R. 1986. *Dark caves, bright visions: Life in Ice Age Europe*. New York: The American Museum of Natural History & W. W. Norton.
- Wilson, D. 1885. Palaeolithic dexterity. *Transactions of the Royal Society of Canada*, Section II, 119–133.
- Wilson, S. C. & Barber, T. X. 1978. The creative imagination scale as a measure of hypnotic responsiveness: Applications to experimental and clinical hypnosis. *American Journal of Clinical Hypnosis*, 20, 235–249.
- Winkelman, M. 1990. Shaman and other “magico-religious healers”: A cross-cultural study of their origins, nature and social transformation. *Ethos*, 18, 308–352.
- Winkelman, M. 2002. Shamanism and cognitive evolution. *Cambridge Archaeological Journal*, 12, 71–86.
- Winton, V. 2005. An investigation of knapping-skill development in the manufacture of Palaeolithic handaxes. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 109–116). Cambridge, UK: McDonald Institute for Archaeological Research.
- Woody, E. & Claridge, G. 1977. Psychoticism and thinking. *British Journal of Social and Clinical Psychology*, 16, 241–248.
- Wright, R. V. S. 1972. Imitative learning of a flaked stone technology – the case of an orang-utan. *Mankind*, 8, 296–306.

- Wurz, S. 2002. Variability in the Middle Stone Age lithic sequence, 115,000–60,000 years ago at Klasies River, South Africa. *Journal of Archaeological Science*, 29, 1001–1015.
- Wynn, T. 1979. The intelligence of the later Acheulean hominids. *Man*, 14, 371–391.
- Wynn, T. 1981. The intelligence of Oldowan hominids. *Journal of Human Evolution*, 10, 529–541.
- Wynn, T. 1985. Piaget, stone tools and the evolution of human intelligence. *World Archaeology*, 17, 31–43.
- Wynn, T. 1988. Tools and the evolution of human intelligence. In R. W. Byrne & A. Whiten (Eds.), *Machiavellian intelligence* (pp. 271–284). Oxford: Clarendon Press.
- Wynn, T. 1990. Natural history and the superorganic in studies of tool behavior. In M. Bekoff & D. Jamieson (Eds.), *Interpretation and explanation in the study of animal behavior. Vol. II: Explanation, evolution, and adaptation* (pp. 98–117). Boulder, CO: Westview Press.
- Wynn, T. 1991a. Tools, grammar and the archaeology of cognition. *Cambridge Archaeological Journal*, 1, 191–206.
- Wynn, T. 1991b. Archaeological evidence for modern intelligence. In R. A. Foley (Ed.), *The origins of human behaviour* (pp. 52–66). London: Unwin Hyman.
- Wynn, T. 1993. Layers of thinking in tool behavior. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognition in human evolution* (pp. 389–406). Cambridge, UK: Cambridge University Press.
- Wynn, T. 1995. Handaxe enigmas. *World Archaeology*, 27, 10–24.
- Wynn, T. 2000. Symmetry and the evolution of the modular linguistic mind. In P. Carruthers & A. Chamberlain (Eds.), *Evolution and the human mind: Modularity, language, and meta-cognition* (pp. 113–139). Cambridge, UK: Cambridge University Press.
- Wynn, T. 2002. Archaeology and cognitive evolution. *Behavioral and Brain Sciences*, 25, 389–438.
- Wynn, T. & Coolidge, F. 2003. The role of working memory in the evolution of managed foraging. *Before Farming*, 2, 1–16.
- Wynn, T. & Coolidge, F. L. 2004. The expert Neandertal mind. *Journal of Human Evolution*, 46, 467–487.
- Wynn, T. & McGrew, W. C. 1989. An ape's view of the Oldowan. *Man*, 24, 383–398.
- Wynn, T. & Tierson, F. 1990. Regional comparison of the shapes of later Acheulean handaxes. *American Anthropologist*, 92, 73–84.
- Zangwill, O. L. 1960. *Cerebral dominance and its relation to psychological function*. Edinburgh: Oliver and Boyd (Henderson Trust Lecture XIX).
- Zwicky, F. 1948. Morphological astronomy. *The Observatory*, 68, 121–143.
- Zwicky, F. 1969. *Discovery, invention, research: Through the morphological approach*. Toronto: Macmillan.

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This book presents new directions in the study of cognitive archaeology. Seeking to understand the conditions that led to the development of a variety of cognitive processes during evolution, it uses evidence from empirical studies and offers theoretical speculations about the evolution of modern thinking as well. The volume draws from the fields of archaeology and neuropsychology, which traditionally have shared little in the way of theories and methods, even though both disciplines provide crucial pieces to the puzzle of the emergence and evolution of human cognition. The twelve essays, written by an international team of scholars, represent an eclectic array of interests, methods, and theories about evolutionary cognitive archaeology. Collectively, they consider whether the processes in the development of human cognition simply made use of anatomical and cerebral structures already in place at the beginning of hominization. They also consider the possibility of an active role of hominoids in their own development and query the impact of hominoid activity in the emergence of new cognitive abilities.

**Sophie A. de Beaune** is Professor of Prehistory at Jean Moulin University-Lyon 3 and Deputy Scientific Director at the French National Center for Scientific Research (CNRS). The author of eight books, most recently *L'Homme et L'outil: L'invention Technique durant la Préhistoire*, she is also director of a book series entitled "Le passé recomposé" at CNRS Editions.

**Frederick L. Coolidge** is Professor of Psychology at the University of Colorado at Colorado Springs. He has published extensively in behavioral genetics, neuropsychology, psychopathology assessment, and cognitive archaeology, with recent articles in *Cambridge Archaeological Journal*, the *Journal of Human Evolution*, and *Journal of Archaeological Research*, among others.

**Thomas Wynn** is Professor of Anthropology at the University of Colorado at Colorado Springs. He has published extensively on the evolution of human cognition, culminating in a target article in *Behavioral and Brain Sciences*, published in 2002.

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