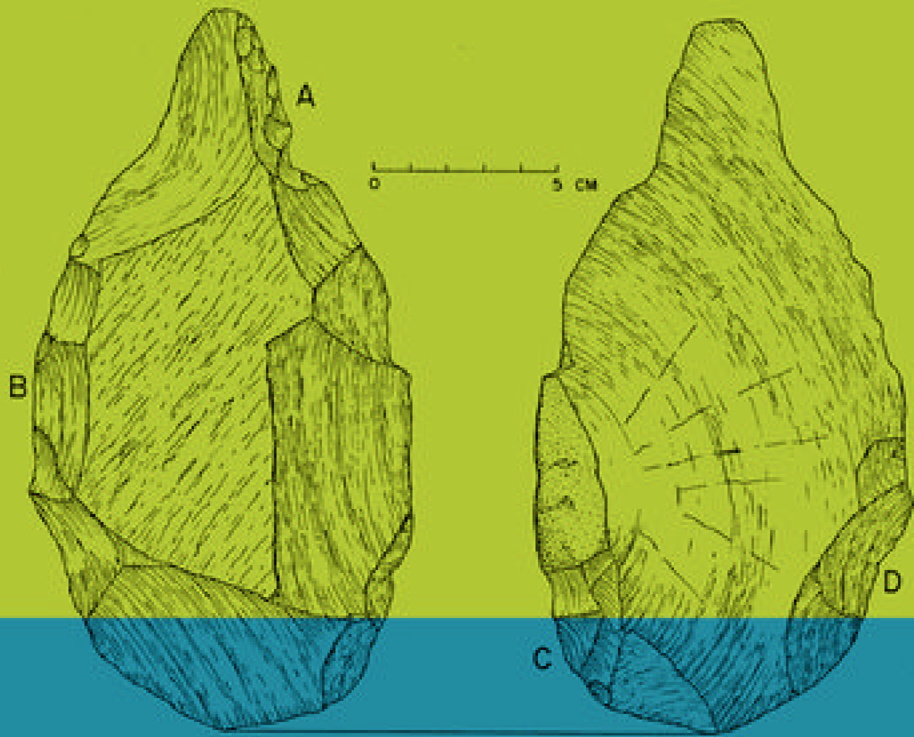

Cognitive Models in Palaeolithic Archaeology

edited by

THOMAS WYNN • FREDERICK L. COOLIDGE

OXFORD

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CONTENTS

PREFACE

Cognitive Models in Palaeolithic Archaeology grew out of a specialized thematic session that we organized for the 2013 meeting of the European Society for the Study of Human Evolution. The previous decade had seen an increasing number of articles and books that included reference to the cognitive capabilities of early hominins, but many of their conclusions were underdetermined in a theoretical sense. It was impossible, based on the evidence alone, to determine which interpretations were more likely. For example, were the engraved patterns found on South African Middle Stone Age artifacts evidence of symbolic thinking or something else? Simply compiling more evidence will never resolve the disagreement.

It has long been our contention that an evolutionary cognitive archaeology is certainly possible but for it to carry any persuasive weight—for there to be a basis for choosing between competing claims—evolutionary cognitive archaeology must be grounded in cognitive science itself. The chapters in this volume all rely on formal cognitive models and thus produce well-grounded claims for a variety of components in Palaeolithic cognition. Because they are well-grounded, they are also open to equally well-grounded critiques, opening the way for productive discussions about the evolution of the hominin mind.

We would like to thank the board of the European Society for the Study of Human Evolution for their support in developing the original session, Joan Bossert and Lynn Luecken at Oxford University Press, and the anonymous reviewer of the original chapter texts.

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Cognitive Models in Palaeolithic Archaeology

1

Evolutionary Cognitive Archaeology

THOMAS WYNN

Introduction

Evolutionary cognitive archaeology (ECA) is a branch of prehistoric archaeology that focuses on the evolution of the human mind. As such, its geographic and temporal remit is vast, encompassing all of human thought from the first stone tools 3.3 million years ago to the appearance of human civilization some 5,000 years ago. Yet despite this huge potential database for systematic research, ECA practitioners remain relatively few. It cannot be that the topic itself is inherently uninteresting—we humans pride ourselves in our intellectual acumen, and surely the story of how this evolved would fascinate many. Instead, the dearth of participants can be traced to the methodological challenge and to the quirks of intellectual history. To study the evolution of mind, one must know something about the mind, and for archaeologists this means engaging a literature with which they have little familiarity. Archaeology and cognitive science share little in the way of a common intellectual history. It is not that the two disciplines are hostile; they just have rarely encountered one another in pursuing a shared goal. Archaeologists are far more likely to be familiar with geography, geology, or history. Moreover, because they are ignorant of basic cognitive science, many archaeologists feel that there is something "soft" about studying the mind or that "paleo-psychology" is somehow akin to dowsing or New Age transcendentalism. But the basic methodological stance of cognitive archaeology is no different from that of other archaeologies. Prehistoric minds are no more remote than prehistoric social systems. Both require careful reasoning about the significance of archaeological patterns, and both require deployment of formal models. Common sense understandings of the mind based on self-reflection are *not* the basis of cognitive science. Instead, cognitive science relies on formal models tested through experimental protocols and sophisticated quantitative techniques. It is not a soft science; its models have tremendous interpretive power. The challenge lies in applying these models to the peculiarities of archaeological evidence.

The evolution of the human mind has been a topic of scientific interest since the time of Darwin and, indeed, was a particular interest of Alfred Wallace (Gould, 2002). Prior to the discovery of hominin fossils, scientists interested in the evolution of mind were limited to the comparative evidence, both zoological and ethnographic. Not surprisingly, given the Victorian enthusiasm for progress and the global expansion of European culture, interpretations were heavily biased by the prevailing opinions of human uniqueness and European superiority. These biases continued even after the discoveries of *Pithecanthropus* by Eugène Dubois and *Australopithecus* by Raymond Dart and largely explain the embarrassing scientific flap over the Piltdown hoax. By the mid-twentieth century, paleoanthropology had become perhaps too reticent to discuss the evolution of mind, reducing it to the single unadorned measure of cranial capacity. But this began to change in the 1960s with the development of replicable techniques for making endocranial casts allowing discussion of brain shape.

Today cognitive evolution, as it is now termed, is the focus of a multipronged assault that engages scholars from several different disciplines. For hominin cognitive evolution, there are four primary approaches, each relying on different datasets and, all too often, different theories. The four are paleoneurology, evolutionary psychology, primatology, and evolutionary cognitive archaeology.

Paleoneurology

Studies of brain evolution, both size and shape, constitute the most often cited evidence of cognitive evolution in the paleoanthropological literature despite the serious difficulties of arguing from brain anatomy to cognitive function. Paleoneurology is the study of the evolution of the brain using fossil remains. Vertebrate fossils occasionally include fossilized brain cases, and, from these, paleontologists can study brain size and also features of shape. Interest in paleoneurology grew dramatically after the publication Jerison's landmark book, *Evolution of Brain and Intelligence* (Jerison, 1973), in which he used endocasts of brain cases to demonstrate a strong correlation among major vertebrate groups between brain shape and salient features of adaptive niche. Brain differences between more closely related taxa are more subtle, both in terms of relative brain size and specifics of shape. The lack of surface detail on endocasts meant that attempts to locate all but the most obvious sulci and gyri were mostly unsuccessful. It was, however, possible to recognize and describe changes in hemispheric asymmetry, including differential enlargement or reduction of some important structures (Holloway, 1983; Holloway, Broadfield, & Yuan, 2004). The enlargement of Broca's cap early in the evolution of the genus *Homo* is arguably the most provocative example. Interpreting observed differences in gross brain anatomy has been much more difficult and, to this day, continues to be the source of much naïve speculation (as when Villa and Roebroeks [2014] asserted that the difference in brain size and shape between Neandertals and modern humans had no behavioral implications). More recently nondestructive/intrusive imaging techniques have supplemented endocasts, and 3-D morphometrics have provided much finer descriptions of shape differences (Bruner, 2003, 2004).

Jerison also introduced the encephlazation quotient (EQ), which is a measure of how much larger or smaller a brain is compared to its predicted size based on body weight. EQ quickly became a popular measure because it enabled paleontologists to compare different taxa in terms of how encephalized they were, the implication being that more encephalized taxa had more neural resources devoted to various higher cognitive functions, including intelligence (the similarity to IQ was probably intended). As a way of comparing large, inclusive taxa (e.g., ungulates vs. rodents), EQ has shown considerable utility but even at the level of comparing primates to one another it is problematic and in studying early hominins it encounters many difficulties, not the least of which is measuring body size (an important component of the calculation).

Evolutionary Psychology

During the 1970s, a second, largely independent approach to human cognitive evolution grew out of the controversy surrounding the application of sociobiological concepts to human sociality. The initial impetus for this approach was E. O. Wilson's seminal *Sociobiology* (Wilson, 1975), which presented social behavior as a Darwinian phenomenon resulting from individuals striving to maximize their own reproductive success. *Sociobiology* was tremendously influential in the study of nonhuman behavior but created a furor when applied to humans. The term "sociobiology" itself became anathema in many anthropological circles, where even today advocates are often treated with derision. But the idea that human sociality can best be understood as a Darwinian phenomenon is a powerful one, and its advocates largely fled to a new academic home—evolutionary psychology. Prior to the 1970s, psychologists rarely concerned themselves with evolution, and when early evolutionary psychologists such as David Buss (e.g., Buss & Barnes, 1986) applied Darwinian models to experimental results, they made an immediate impact.

Evolutionary psychology relies almost exclusively on a single method of enquiry—reverse engineering. If one can identify what a cognitive component is designed to do—usually through carefully designed experimental protocols—one can understand how and why it evolved. Evolutionary psychologists coined the concept of environment of evolutionary adaptedness (EEA), which is a heuristic that encompasses conditions in the evolutionary past that selected for psychological profiles in the present. Note that actual evidence about the evolutionary past is not required, only a thorough description of the psychological trait of interest. Evolutionary psychology is today a robust discipline with several influential journals.

Primatology

The third leg of the evolutionary approach to cognition is supplied by primatology. The comparative method has long been a pillar of evolutionary science, and knowledge of primate anatomy and behavior has been central to reasoning about human evolution since the time of Darwin, Owen, and Huxley. Before one can even begin to ask about hominin cognitive evolution, it is necessary to know what is cognitively unique about hominins (in evolutionary terms, the derived characteristics). Knowledge of our nearest evolutionary relatives provides this information. But primatology supplies much more. Because hominins are primates, they have been under many of the same evolutionary constraints as other primates. One such constraint of particular relevance to cognitive evolution is the tradeoff between brain size and gut length in primate evolution. As an empirical generalization, primates with diets of low-quality food such as leaves have longer guts and smaller brains than primates who focus on foods with denser nutrition. This gut length–brain size equation played out in hominin evolution as well (Aiello & Key, 2002; Aiello & Wheeler, 1995) but, without extensive knowledge of nonhuman primates, paleoanthropologists would not have known to look for it. The importance of social life in the evolution of cognition was first noted by primatologists (Jolly, 1972). Byrne and Whiten's 1988 *Machiavellian Intelligence* (Byrne & Whiten, 1988) identified life in complex, often multimale social groups as the greatest challenge to an individual primate's problem-solving ability. This focus on sociality has motivated investigation into such important cognitive abilities as deception, theory of mind (Dunbar, 1993), social learning (Byrne & Russon, 1998), and cheater detection (Cosmides, 1989). All are now important considerations for hominin cognitive evolution.

Use of primate data and models is not without challenges. The two primary methodological threads of primatology—experimental and ethological—draw on different intellectual traditions and often reach conclusions that are hard to rectify. Primates in natural situations are often observed solving problems that the same species fails to solve under controlled laboratory protocol (tests of theory of mind are a good example; Tomasello & Herrmann, 2010). Nevertheless, knowledge of primate cognition will continue to be a primary source of concepts and models applicable to hominin cognitive evolution. Indeed, one of the current leading hypotheses for hominin brain evolution, the *social brain hypothesis*, was grounded initially in the comparative primate evidence (Dunbar, Gamble, & Gowlett, 2014). However, even though it is essential to understand hominins' primate heritage, this knowledge base cannot on its own inform us about the critical issue—how hominins evolved to be different.

A Brief (and Idiosyncratic) History of Evolutionary Cognitive Archaeology

Paleontology, the comparative method, and reverse engineering are methods that apply to any evolutionary question, and they will continue to provide important insights into hominin cognitive evolution. But the study of hominin evolution has a fourth methodological avenue that is almost unique to the taxon—an archaeological record of actual activities performed by hominins in the evolutionary past. Archaeological remains are physical traces of past activities that have survived into the present. Such behavioral traces should be a treasure trove of data attesting to the cognition of long-vanished individuals. Yet for reasons peculiar to the history of Anglophone archaeology, this obvious avenue of inquiry has been almost entirely neglected by archaeologists themselves.

The modern era of evolutionary cognitive archaeology began, ironically, not with the work of an archaeologist but with a thoughtful review written by the dean of American paleoneurologists, Ralph Holloway. In a 1969 article in *Current Anthropology*, he broadened his approach to address the significance of stone tools associated with early hominin fossils. At the time, linguistic and structural models of culture dominated American anthropology, and, not surprisingly, Holloway applied this perspective to the early stone tools, arguing that the patterned action required to make these tools was akin to the regularities of syntactical communication and that therefore structurally patterned culture must have been a leading element in the evolution of the early hominin brain and cognition. This was a landmark paper for human paleontology and for the thread of research that became ECA. In retrospect, two components of Holloway's argument stand out: (1) the explicit use of archaeological remains as evidence of cognition and (2) the use of an established theory, in this case, a linguistic/structural model of culture. Unfortunately, although Holloway's conclusion was well-received, his method had little influence on archaeological practice, which was then entering the chaotic days of the "New archaeology," out of which a decidedly materialist/ecological perspective came to dominate Palaeolithic research.

There were a number of reasons for the ascendancy of materialist/ecological thinking in the Palaeolithic research of the 1970s. First, the materialist approach provided a refreshing alternative to the sterile descriptions of stone tool typologies that had dominated Palaeolithic archaeology for more than a century. Instead of industries and variants, archaeologists now wrote about ecology, adaptation, and natural selection. Not only did such accounts dovetail better with the growing wealth of fossil hominins, they also painted a picture that was much easier for nonspecialists to understand. Here was a story of evolutionary success and the triumph of our ancestors. Public attention and funding naturally followed. Second, materialist theory is almost ideally suited to Palaeolithic remains. The "means of production" is the leading element of most materialist theories and is also the domain of human activity that leaves the most archaeological remains. If other components of hominin behavior and culture were direct or indirect consequences of technical and subsistence activities, then archaeologists need only provide more thorough accounts of prehistoric productive systems in order to reveal everything of importance about prehistoric lifeways. The challenge became technical—how to extract more and more detailed accounts of what hominins ate, how they acquired it, and how they made and used tools. Other questions almost disappeared from Palaeolithic enquiry. Finally, one of the more forceful characters in the history of American archaeology, Lewis Binford, was an active and vociferous advocate of the materialist approach. He used his famously acerbic critical faculties both to drive the discipline in his favored direction and to disparage the few alternative voices. At the time, Palaeolithic specialists were few enough that one individual could, in fact, wield tremendous influence. The result was a marked improvement in the rigor of materialist arguments and a hostile environment for every other approach.

Between 1969 and 1979, there was only one significant foray into the cognitive domain by an established Palaeolithic specialist. This was Glynn Isaac's article in a special issue of the *Annals of the New York Academy of Sciences* devoted to language evolution (Isaac, 1976). In the early 1970s, Isaac had been largely responsible for transforming the archaeology of early human evolution from a focus on typology to a focus on ecology and adaptation (Sept & Pilbeam, 2011). But he was not indifferent to provocative time-space patterns, and, in the 1976 paper, he introduced two descriptive concepts that he felt might inform scholars about language. The first, "differentiation," was not just variety of form, which would always occur naturally, but instead was intentional imposition of different forms by the stone knapper. It is here that Isaac ventured into the cognitive. Differentiation was "The degree to which there were distinct target forms in the minds of the craftsmen" (pp. 279–280). His second new usage was "modality," which was a descriptive term for differentiation based on the metaphor of a topographic surface. Isaac then suggested that the increase in differentiation and topographic complexity demonstrated by early lithic industries reflected an increase in the complexity of rules and, by extension, the linguistic rules of syntax. Two features of this analysis bear mention in the context of the history of ECA. First was his use of "target forms." This was the idea that tools existed as mental images in the minds of knappers; it also appeared in the literature of the time as "mental template" (and indeed can be found in writing to this day). Although certainly cognitive in intent, this concept was not taken from the psychology of the day. It was, in fact, introduced to archaeology by James Deetz (1967) and was based on intuition rather than psychological research. The second point concerns language. In the late 1960s and 1970s, structuralism was the predominant theory in anthropology, and language was considered to be the model structured system, to the degree that it came to be seen as the most defining human characteristic and the model for other structured behavior. Isaac's paper was provocative and could have provided a starting point for more active investigation of cognition in the past. That it did not is primarily a testament to the overwhelming power and success of materialist/ecological models in the Palaeolithic research of the day. But two of its components continued on the peripheries of research—the ill-defined mental template and the dominance of language when referring to the mind.

In 1979, three articles appeared, quite independent of one another, which planted the seeds of a more serious archaeological study of cognitive evolution. The first was by John Gowlett and appeared in the journal *Nature* (Gowlett, 1979). Very much in the mode of Holloway and Isaac (cited by Gowlett), Gowlett emphasized "design regularities" and increasing complexity over the course of cultural evolution. He made a specific appeal for the use of archaeological remains for "the study of intellectual developments" and invoked goal-seeking behavior, cognitive mapping, and especially forward planning in his discussion of early stone tools. These terms emerged from his examination of trends in the archaeological record itself; there was no cited source from any of the branches of cognitive science. The significance of this paper lay in its clear evocation of a role for cognition in hominin evolution and also for its reliance on specific patterns in the archaeological record.

The second 1979 paper was written by two biological anthropologists, Sue Taylor Parker and Kathleen Gibson (1979), who approached cognitive evolution, and language in particular, by applying a formal model from developmental psychology to the paleoanthropological record. In the 1960s and 1970s, Jean Piaget was the world's leading developmental psychologist. Over fifty years of active research, he had proposed and elaborated a stage model for human child development, arguing that all children passed through an invariant sequence of increasingly more logical and powerful forms of reasoning. Using a long-neglected stance in evolutionary studies, that of ontogeny informing phylogeny, Parker and Gibson applied Piaget's scheme to nonhuman primate cognition and to the early archaeological record. They argued that early hominins, *Homo habilis* in particular, fell slightly further up Piaget's sequence of stages and substages than apes such as chimpanzees. This was a remarkable conclusion. For the first time, paleoanthropologists actually applied an independent scale of cognition and used it to contrast apes and early hominins. Parker and Gibson's archaeology leaned heavily on Isaac's reconstruction of home bases for *Homo habilis*, rather than specific archaeological patterns. As it turned out, Isaac's reconstructions were shown to be overly optimistic (initially by Binford), which weakened Parker and Gibson's specific comparison, but they clearly demonstrated the potential of using a formal cognitive model.

At the same time that Parker and Gibson were developing their model, and again independently, Piaget became the basis for another archaeological study, that of Thomas Wynn (Wynn, 1979, 1981, 1985, 1989). Wynn's method differed from that of Parker and Gibson. He used Piaget's model, especially the work in spatial cognition (Piaget & Inhelder, 1967), to compile a list of attributes that he could apply to artifacts and used the results to formulate a phylogenetic sequence and timing for the evolution of spatial cognition. Because Piaget advocated for general intelligence, Wynn could argue (probably wrongly) that the evolution of spatial cognition revealed the sequence for general intelligence, placing modern intelligence as early as 300,000 years ago.

The appearance of Parker and Gibson (1979) and Wynn (1979) marked the first explicit application of a psychological model to the Palaeolithic record and exemplified the potential of the approach to enhance understanding of cognitive evolution and human evolution in general. Use of a developmental model enabled them to perform three kinds of analysis that other approaches to cognitive evolution could not. The first was assessment. Piaget's theory is a stage model with well-defined stages and substages, and both Parker and Gibson and Wynn reached very specific conclusions about where on this scale Oldowan and later Acheulean hominins, respectively, fell. This, in turn, enabled comparison. One of the basic tenets of Piagetian theory is that the stage model is true generally, not just for child development but for all developmental sequences. In practice this meant that Parker and Gibson and Wynn could compare their target groups to other primates and other hominins. Finally, because Piagetian theory argued for stages of general intelligence, it enabled Parker and Gibson and Wynn to extrapolate to behaviors not directly visible in the archaeological or fossil records. Parker and Gibson were able to make suggestions about the linguistic competence of Oldowan hominins, while Wynn focused more on social extrapolations. The resulting conclusions of both papers ran counter to features of the standard story of early human evolution, which at the time leaned on the "Man the Hunter" model of human evolution derived from knowledge of modern hunters and gatherers (Lee & DeVore, 1968). Parker and Gibson's and Wynn's Oldowan hominins appeared much more apelike than the proto-modern human hunters and gatherers of many reconstructions.

The explicit nature of the Piagetian model made Parker and Gibson and Wynn susceptible to informed criticism on several levels. Critics could assess the theory itself, the way that Parker and Gibson and Wynn articulated with the theory, and the reliability of the data they used. As it turned out, weaknesses in the theoretical model itself were arguably the most important causes of the ultimate demise of the approach in human evolutionary studies. Ironically, by the late 1970s, Piagetian theory had begun to lose its hold on developmental psychology. The primary difficulty was the failure of its strict stage model. Although the general sequence was sound, children did not pass through the stages in lock step. A child often tested at one stage in one domain and at a different stage in another domain. Indeed, the whole notion of general intelligence was found wanting. Also, Piagetian theory was very much an early-twentieth-century theory. It took no account of the brain and little account of the sophisticated quantitative methods of contemporary experimental psychology. In the 1970s and 1980s, neuroscience exploded in popularity, and interest in how brains produced cognition became a central concern.

Parker and Gibson and Wynn continued to apply Piagetian theory through the 1980s. As a method for primatology, Parker and Gibson's approach yielded important insights, and several other scholars adopted it (Parker & Gibson, 1990; Russon & Begun, 2004). Wynn eventually abandoned the approach entirely, primarily because the archaeological record itself, like the record of human children, failed to conform to predictions of the theory. In Piaget's model of the development of spatial cognition, fully Euclidean spatial thinking develops after a stage during which projective concepts dominate spatial organization. In the archaeological record, projective and Euclidean concepts appeared at the same time. Despite the ultimate failure of the Piagetian approach, three points bear emphasis. First, the analyses were explicit and open to refutation, a quality quite missing from more common-sense musings. Second, some of the specific conclusions about cognitive evolution have survived the demise of the approach. The assessment of the Oldowan as essentially an ape technology has received increasing confirmation over the subsequent three decades (Byrne, 2004; Davidson & McGrew, 2005; Wynn, Hernandez-Aguilar, Marchant, & McGrew, 2011). Third, even more than the articles by Holloway and Isaac, the Piagetian approach of Parker and Gibson and Wynn demonstrated how much more could be done with the archaeological record if one applied appropriate theoretical models.

In the 1980s, most archaeological theory swung away from the materialist orthodoxy introduced by processual archaeology. In reaction to the prosaic, often dreary, accounts of prehistoric productive and economic systems, many archaeologists turned their attention to symbolism and social behavior. Some, inspired by the writings of postmodernists in literary theory and sociology, abandoned the pretense of a scientific archaeology altogether in favor of more self-conscious interpretations of the past (Hodder, 1991). Others, such as Colin Renfrew at Cambridge University, advocated for an updated form of processualism that retained the methodological rigor but replaced narrow materialist perspectives with a broader orientation that granted organizing power to minds and cognition, with a special attention to symbolic thinking. Indeed, Renfrew was arguably the first to use the term "cognitive archaeology" (Abramiuk, 2012). Renfrew's approach did not directly engage cognitive models such as Piaget's. Instead it drew from semiotics and sign theory, the works of Charles Sanders Peirce (Houser & Kloesel, 1992), Saussure (1966), and Jakobson (Jakobson & Halle, 1971) in particular. Palaeolithic specialists, it should be noted, largely ignored this counter-revolution in archaeological theory and continued to churn out materialist/adaptationist accounts of the evolutionary past (and, indeed, continue to do so to this day). But the few who did develop and maintain an interest in cognition almost all embraced Renfrew's stance and focused on symbol systems and language or followed Clive Gamble's (Gamble, 1999) lead and turned to models of social action. Outside of Wynn's continued adherence to Piaget, there were no applications of models derived from cognitive science or psychology. This changed in 1989 with the publication of an article co-authored by an archaeologist and a psychologist.

Rather than simply apply a single cognitive model to Palaeolithic remains, as Parker and Gibson and Wynn had done, archaeologist Iain Davidson and psychologist William Noble used a psychological model as the primary grounding for a theoretical model of their own (Davidson & Noble, 1989, 1993; Noble & Davidson, 1996). In keeping with the emphasis on language that characterized most discussions of hominin cognitive evolution in the 1980s, Davidson and Noble developed a sophisticated hypothesis for the evolution of language based in the ecological psychology of James Gibson (J. Gibson, 1986; no relation to K. Gibson). Unlike Piaget and most cognitive psychologists of the time, Gibsonian psychologists eschewed the notion that cognition consisted of mental states or representations through and by which perceptual information was processed. Instead, organisms directly apprehended energy fields emitted by the environment and responded directly. This was not just an alternative model of cognition, it was an alternative understanding of the ontological status of the mind. For Davidson and Noble, only language itself, as a form of reflexive communication, could perform the role of epistemic mediator. But in the absence of such reflexive ability in prelinguistic hominins how could language have emerged in the first place? Davidson and Noble argued that only through depiction, preceded by mimicry, could language evolve and that, therefore, the emergence of depiction in the archaeological record reliably marked the advent of language. The Davidson-Noble hypothesis was a strong one, arguably the strongest archaeologically linked argument for language origin yet proposed. It was based in an explicit model of cognitive function that made equally explicit predictions about the archaeological record. Its clarity also meant that it was susceptible to critique on both the theoretical level and the evidential level (i.e., the very best kind of argument). It also had a significant impact on the standard narrative of hominin evolution, at the time based largely on paleoneurology, in which language was seen to have evolved early as one of the defining characteristics of the hominin line. Davidson and Noble placed the evolution of language very late indeed, as the advent of depiction occurred well after 100,000 years ago. They forced a generation of scholars to think much more carefully about the implications of archaeological evidence for language and mind. They were also notable in being the first serious collaboration between a psychologist and a Palaeolithic archeologist, attesting to the kinds of insights possible from truly interdisciplinary scholarship.

Davidson and Noble's invocation of a nonrepresentational model foreshadowed developments that arose a decade later, but, in the main, the cognitive/representational perspective continued to predominate in cognitive evolutionary studies. Adhering to a cognitivist position, neuropsychologist Merlin Donald (1991) tackled the entire sweep of hominin cognitive evolution in his *Origins of the Modern Mind*. His argument fit well with the academic zeitgeist of the time. The brain sciences were undergoing dramatic growth and popularity, and Donald's background in neuropsychology enabled him to develop a plausible model that was very influential in cognitive archaeology, especially to those who gave language precedence. However, unlike Parker and Gibson, Wynn, and Davidson and Noble, he did not use his model to attempt close analysis of archaeological data, relying instead on generalizations about the Palaeolithic gleaned mostly from secondary sources.

The 1990s saw a dramatic rise in interest in cognitive evolution. Impetus came from developments in neuroscience, especially neuroimaging, but also from evolutionary psychology (Barkow, Cosmides, & Tooby, 1992; Buss, 2003; Buss & Barnes, 1986; Tooby & DeVore, 1987) and primatology (K. Gibson, 1990, 1993). Among these was one of the first attempts at a truly interdisciplinary approach to the topic, *Tools, Language, and Cognition in Human Evolution* (K. Gibson & Ingold, 1993), whose papers grew out of a Wenner-Gren International Symposium organized by Kathleen Gibson and Tim Ingold. With only a few exceptions, archaeologists themselves continued to remain largely on the sidelines, providing up-to-date descriptions, but avoiding direct immersion in the interpretive debates. Three events helped change this. The first was the establishment of the McDonald Institute at Cambridge University, part of whose research mission was the advancement of cognitive archaeology. The institute established *Cambridge Archaeological Journal*, which provided a venue for publication of cognitive archaeology. This was followed in 1996 by the publication of two books, Mithen's *The Prehistory of Mind* (1996) and Noble and Davidson's *Human Evolution, Language, and Mind: A Psychological and Archaeological Inquiry* (1996). These were books that had the same evolutionary scope as Donald's 1991 volume but which were written by archaeologists. Between them, they demonstrated the active role that archaeologists could play in the study of cognitive evolution. Noble and Davidson expanded on the perspective introduced in their 1989 paper, and Mithen based his analysis on models from cognitive and developmental psychology, in particular the work of Fodor (1983), Gardner (1983), and Karmiloff-Smith (1992). Mithen argued that the overriding theme of human cognitive evolution was the relationship between narrow modules of cognition that evolved to solve specific evolutionary problems and a more general problem-solving ability that he labeled cognitive fluidity. The final "big bang of human culture" that occurred some 50,000 years ago was powered by the final development of cognitive fluidity that enabled cross-modal and metaphorical thinking and creativity. As a syncretic model, Mithen's was arguably not as robust as that of Noble and Davidson, but it adhered to the standard Cartesian separation of mind and body and was therefore more accessible to general readers. Mithen was (and is) a gifted writer, and he made effective use of several rhetorical metaphors to deliver arcane ideas in understandable form. He also pitched the book at a general educated audience, rather than archaeologists or cognitive scientists, which resulted in scholars of all stripes reading the book and seeing the potential of an evolutionary cognitive archaeology.

By the end of the 1990s, evolutionary cognitive archaeology had established itself as an important method in the study of hominin cognitive evolution. The epistemological case had been made. From that point, evolutionary cognitive archaeologists began to explore a variety of theoretical perspectives on the Palaeolithic record, resulting in an eclectic discipline than cannot be summarized in a few paragraphs. Indeed, showcasing some of these approaches is the primary goal of this volume. But what makes for an effective argument in evolutionary cognitive archaeology?

Appropriate Models

An effective evolutionary cognitive archaeology must be interdisciplinary. In isolation, archaeology is simply a set of methods for the study of the past, and although these methods vary according to peculiarities of local academic practice, they have no inherent shared understanding of the people who produced the record in the first place. For this, archaeology has always drawn on ideas and theories developed in disciplines that study living people. A good archaeological interpretation is explicit about the source of its interpretive ideas and explicit about how the archaeological evidence articulates with these ideas. Implicit theories are rarely a good basis of analysis, and yet the history of archaeology is replete with examples of interpretations drawn from vague, "common-sense" understandings of the human condition, including at times racist, sexist, and culturally elitist "truths." Unfortunately, this vagueness extends to archaeological treatments of the mind, where it is still common to find reference to ill-defined, pseudo-cognitive terms such as "abstract" or "complex." It is possible to do better, but improvement in cognitive archaeology requires that archaeologists consult the disciplines that study the mind. Because archaeology is not a methodology commonly encountered in cognitive science or psychology programs, one cannot expect to go to these literatures and find theories designed to fit archaeology's methodological peculiarities. The onus falls on the archaeologist to access and understand the theories, models, and concepts of these allied but nevertheless remote disciplines. How, then, does the archaeologist proceed?

There are two ways for an archaeologist to approach the cognitive science literature—via theoretical purity or pragmatism. The first identifies a model of cognitive function that is convincing and hammers out archaeological sequelae that allow application of the theory to the past; one recasts the evidence so that it articulates with the theory (Wynn's application of Piagetian theory is an example). Alternatively, one can take a more pragmatic approach and select a model or models that can be modified to accommodate a set of activities one finds in the archaeological record and adjust the model accordingly (Davidson and Noble's discussion of depiction is an excellent example). Here, the overarching power of the theory is not as important as one's ability to operationalize it for the evolutionary past. Either approach can, and has, provided insights into the evolution of mind that are theoretically grounded and therefore a powerful basis for explanation.

It is important to note at this point that *a comprehensive theory of cognitive function does not yet exist*; different theories have different strengths, and not all are appropriate for all questions. Since the 1990s, ECA practitioners have taken a variety of different, cognitively grounded approaches to interpreting archaeological remains. They can be grouped on the basis of underlying cognitive models.

Neuroarchaeology: Neuroarchaeology strives to describe the patterns of neural activation that generated archaeologically discovered activities. Methodologically, it is primarily experimental. Typically, an experimental participant will perform an activity reconstructed on the basis of archaeological remains, after or during which a neuroimaging device of some sort records the patterns of neuroactivation. If the experiment tests similar activities from different points in human evolution (e.g., stone knapping), it is possible to identify evolutionary changes in the patterns of activation. Such studies are subject to the caveats attaching to all neuroimaging studies, such as coarseness of resolution, and have the added drawback of using modern brains as proxies for early hominin brains. Nevertheless, neuroarchaeology has proved a powerful tool for investigating the evolution of cognition and, more exciting, has begun to provide results that are of interest to the brain sciences in general (Hecht et al., 2014; Putt, Woods, & Franciscus, 2014; Stout, Passingham, Frith, Apel, & Chaminade, 2011; Stout, Toth, Schick, Stout, & Hutchins, 2000; Uomini, 2006).

Cognitive Neuroscience: The most commonly encountered formal models in ECA are taken from cognitive neuroscience (Gazzaniga, 2009), which is a broad approach based in both the experimental results of cognitive psychology and the use of neuroscience techniques, including neuropsychology (study of individuals with brain damage/pathology) and neuroimaging. Cognitive neuroscience has tackled an immense array of cognitive abilities, and many of its models are adaptable to archaeological evidence. Among the cognitive neuroscience domains employed by ECAs are vision (Hodgson, 2000, 2009, 2011), neuroaesthetics (Martín-Loeches, Chapter 6, this volume), working memory (Coolidge & Wynn, 2001, 2005; Wynn & Coolidge, 2010), spatial cognition (Wynn, 1989, 2000, 2002, 2010), numeracy (Overmann, 2013; Overmann, Wynn, & Coolidge, 2011), and constructive memory (Ambrose, 2010).

Developmental Psychology: Even though developmental models played an important role in the early stages of ECA (Mithen, 1996; Parker & Gibson, 1979; Wynn, 1979, 1981, 1985, 1989), enthusiasm waned in the 1990s. The major exception has been Moore's (Moore & Brumm, 2006) use of Greenfield's (1991) model of early logical development to help sort out the basic cognitive challenges of stone knapping.

Information Processing: One of the long-standing stalwarts of cognitive science has been the study of information systems. Although often associated with the study of artificial intelligence and robotics, it also has an important branch that studies human psychology from this perspective. Most such approaches have focused on static models that are of limited use to evolutionary science, but Philip Barnard (Barnard, 2010; Barnard, Duke, Byrne, & Davidson, 2007) has developed a dynamic model of increasingly more powerful cognitive states that can be applied to both ontogeny and phylogeny.

Social Cognition: Concepts derived from studies of social cognition have proved fruitful in ECA. Some of these concepts, such as cheater detection, have been borrowed from evolutionary psychology, where they are especially well-developed. Others have been drawn from cognitive ethology. Theory of mind has proved to be especially influential. Dunbar (Dunbar, 1993, 2009; Dunbar et al., 2014) has famously used it to flesh out his theory of brain size and social group size. More recently, Henshilwood and Dubreuil (2009, 2011) have made more effective use of it in defense of their symbolic interpretation of the Blombos beads. For earlier developments, archaeologists James Cole (2014, Chapter 8, this volume) and Ceri Shipton (2010) have worked through some of the implications of Dunbar's social brain hypothesis making explicit use of the archaeological record, including the enigmatic Acheulean handaxe.

Symbolic Approaches: Although most semiotic theories are not cognitive per se, they have been and continue to be important considerations in ECA. What is perhaps surprising about many treatments of symbolism in the Palaeolithic is the rarity with which adherents consult and employ formal models of symbolic systems. Even such stalwarts as Peirce and Saussure receive few references. Thus, despite its popularity, it tends not to be well-founded on a theoretical level. There continues to be a great deal of loose reference to symbolic culture, especially in the contentious literature surrounding Neandertal cognition (Villa & Roebroeks, 2014), but, absent solid grounding in either semiotic or cognitive theory, little progress can be made. Noted exceptions to this theoretical laxity have been the work of Davidson and Noble, discussed earlier, and more recently the work of Henshilwood (Henshilwood & Dubreuil, 2011), Rossano (2009), and Malafouris (2013). Beginning in the 1990s, April Nowell (Nowell, 2001, 2013; Nowell & Davidson, 2010; Nowell & d'Errico, 2007) also brought a sophisticated understanding of symbolic systems to some of the more controversial evidence of the Palaeolithic record.

Non-Cartesian Approaches: Cognitive neurosciences, and most allied fields, are committed to an essentially Cartesian view of the mind in which cognition consists of internal representations generated by neural substrates. From this stance, cognitive evolution consisted of increasingly powerful or adaptive internal representations. This view of an internal mind as separate from an external body has come under serious challenge, first from the ecological psychology of James Gibson and more recently from the perspective known as situated or embodied cognition (Clark, 1997; J. Gibson, 1986). Gibson (1986) considered cognitive psychologists' reliance on internal representations to be misplaced. Instead, he argued that neural circuitry directly apprehends energy fields in the environment and responds directly, without building an internal proxy for the outside world. An archaeological application of ecological psychology should, in theory at least, have distinct advantages over representational models because it would eschew the use of an "epistemic mediator" (Wagman, 2002) and focus on the direct context of cognition and available neural resources. However, despite the logical advantage, the approach has not been popular in ECA. The best examples are those of Noble and Davidson (1996) on depiction and Bril and colleagues (2012) on early stone knapping.

A related approach arose in the 1990s, initially as a reaction to artificial intelligence's failure to build robots that could perform such seemingly simple tasks as catching a thrown ball. In a central processing system, such as the kind envisioned by most cognitive approaches, the solution would be achieved by computing the trajectory and apparent velocity of the ball using representations of various kinds and thereby determining the location at which the ball would fall. It turned out that peripherally based systems without a central processor performed more efficiently and reliably (move until the ball is perceived to stop and stand there). This shift in focus came to be known as embodied, extended, or situated cognition. Extreme advocates of situated cognition argue that the cognitive sciences must do away with representationalism entirely, and, in this sense, they agree with the ecological psychologists.

Situated cognition focuses on the roles that peripheral resources such as bodies and tools play in cognition. If tools are not just passive objects controlled by internal representations, but active agents in cognition, then archaeology has an even greater potential to inform cognitive science about the evolution of cognitive systems. To date, the most forceful and articulate case for situated cognition in archaeology has been the work of Lambros Malafouris (Malafouris, 2008, 2010, 2013).

A Mosaic of Cognitive Evolution

The most effective ECA studies have focused on fairly circumscribed cognitive abilities—theory of mind, spatial cognition, working memory, and so on. Together, these studies present a mosaic pattern, and, indeed, this is arguably the most significant general conclusion to be drawn from ECA. The human mind did not evolve gradually as a unified problem-solving computer that increased in capacity. Instead, different cognitive abilities had different evolutionary trajectories. Spatial cognition, for example, acquired its modern features well before half a million years ago (Hodgson, 2011; Wynn, 2002), but theory of mind does not appear to have acquired modern levels of intentionality until much more recently, sometime after 200,000 years ago (Dunbar et al., 2014; Henshilwood & Dubreuil, 2011). A mosaic pattern does not require adherence to a massively modularized model of the human mind, but it does suggest that selective environments changed over the course of human evolution, with cognition responding as able. Of course, material culture was a component of these selective environments, and ECA has begun to document the active role of material culture in cognitive evolution (number concept is a good example; Malafouris, 2013; Overmann et al., 2011).

The chapters that follow illustrate the application of several explicit cognitive models in Palaeolithic research. They are not an exhaustive sampling, but they do present a variety of different models. The editors have made no attempt to enforce a standardized perspective or epistemological stance. No unified picture will emerge; ECA is a very long way from producing a general account of hominin cognitive evolution.

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2

The Expert Cognition Model in Human Evolutionary Studies

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Introduction

The human mind is not a single cognitive phenomenon. It consists of many interconnected networks, each of which has its own evolutionary history. One such system that has been underappreciated in evolutionary studies, but which governs many activities in the modern world, is skilled technical cognition. Unfortunately, this kind of thinking is not held in high regard in academic discourse where verbal and mathematical thinking are the primary tools of scholarship. And yet, for most of human evolution, day-to-day technical thinking was almost certainly more important to the evolutionary success of our ancestors. Even archaeologists, for whom technical remains are the primary data source, have tended to privilege language and symbol use in discussion of the modern mind (d'Errico et al., 2003; Henshilwood, 2007; McBrearty & Brooks, 2000; Mellars, 1989; Mellars, Boyle, Bar-Yosef, & Stringer, 2007). Thus, the evolution of technical cognition is long overdue as a serious focus for evolutionary cognitive archaeology.

A serious difficulty looms immediately: there are no well-developed cognitive models of technical cognition. Over the past century and a half, archaeologists have learned a great deal about stone tools, how they were made, how they were used, and how they were discarded. Using refitting, experimental replication, and spatial analysis archaeologists are able to reconstruct virtually the entire sequence of a tool's use-life, something termed a *chaîne opératoire*. The concept itself was proposed by Leroi-Gourhan (1964) and initially carried implications derived from his theory of technics, but, as practised today, *chaînes opératoires* generally lack explicit cognitive justification except perhaps through vague allusions to complexity and hierarchy, which in the absence of theory are more likely than not impositions on the part of the analyst.

Cognitive psychologists and neuroscientists have investigated components of technical thinking, including haptic perception, spatial cognition, and apraxia to mention just a few relevant cognitive domains. Such research isolates experimentally manageable components and studies variability or the neural substrates responsible (via neuroimaging). But such simple components miss a great deal that is inherent in the production and use of technology. Such reductionism is hard to avoid in experimental science. Real-world activities are complex and messy, making it very difficult to control variables. Recently, Stout and colleagues have used neuroimaging to investigate the neural activity underpinning stone knapping (Hecht et al., 2014). Not surprisingly an extensive area of the frontal, parietal, and temporal lobes is engaged in even simple stone knapping, and it is almost impossible to sift through this very complex picture (literally) to describe what is happening at a cognitive level. They have been able to identify some tentative differences in neural activation between simple knapping and the knapping of a handaxe, but it is hard to translate these findings into specific cognitive abilities. Although the research is ground-breaking in its method and will yield important insights into cognitive evolution, it is not a model of technical cognition that can yet be applied in other domains.

The dearth of experimentally based models of technical thinking is not perhaps so surprising. Work of cognitive anthropologists (Gatewood, 1985; Hutchins, 1995; Keller & Keller, 1996) has clearly established that technical thinking is not simple. It is a complex activity that engages motor systems, perceptual systems, and planning systems. Moreover, it is almost always embedded in a social context, with its own set of cognitive considerations. Experimental approaches can isolate many of these components and study how they develop, how they vary, and, as with Stout and colleagues, how the brain lights up, but the entire package is difficult to model. Until someone proposes a comprehensive model of technical thinking it is necessary to turn to models of similar systems. The cognitive domain we find to be most similar to cognitive anthropological accounts of technical production and application is that of expert performance, also known as expertise.

Expert Performance

Psychologists have long been fascinated by individuals who demonstrate extraordinary abilities—chess masters, virtuoso musicians, mnemonists (Ericsson & Kintsch, 1995; Ericsson, Patel, & Kintsch, 2000; Gobet, 1998; Gobet & Simon, 2000). Impressive anecdotes abound: chess masters who beat multiple opponents while blindfolded, Bach improvising a four-part fugue, imams who regularly recite the entire Koran from memory. How do they do it? As it turns out, it is not as mysterious as it seems, and indeed all of us can do it to some degree, especially in our own areas of expertise. Perhaps the most studied of the expert domains is chess, and because chess is familiar to almost everyone, it provides a good initial example.

Imagine a chess master playing several simultaneous games of blindfolded chess, winning every one. He or she must not only remember the positions of scores of pieces, but must perform in-depth analyses very rapidly, with few or no mistakes. Cognitive psychologists are in general agreement about the behavioral characteristics of this kind of expert performance:

1. Novices require years to attain mastery. Ten years and thousands of repetitions are the numbers most often cited in the literature. Most chess players take a decade or more to achieve master status. The rare precocious master is most often a teenager who has played for years and thousands of games.
2. The expert performs at a high level of accuracy and reliability, making few "unforced" errors. In master's level chess, even a single mistake usually leads to a loss.
3. The expert makes rapid, in-depth, assessments of problems. The blindfolded master rarely lingers over a move. Once informed of an opponent's move, the master almost always has an immediate appropriate response. The result is a high level of flexibility enabling the expert to adjust appropriately "on the fly." Chess masters are famously able to "see" the game several moves in advance, thus preparing for all serious eventualities.
4. Experts can be interrupted and return to a task or problem with little or no loss of information. In a blindfolded test of multiple games, the master must constantly switch attention from one game to another, but still somehow retain all of the information for each game.
5. Experts learn new material very rapidly. Masters learn new openings effortlessly.
6. Expert performance is limited to narrow domains of activity. Chess masters have no advantage in checkers or Go.
7. Experts' responses appear largely automatic, requiring little in the way of active attention.

Expertise in the guise of master-level performance is impressive, but as a style of thinking it is not limited to a talented few. It is in fact a very common form of cognition. We all have domains of expertise: driving an automobile, keyboarding, cooking, and so forth. Driving a motor vehicle is one common example of expertise practised by many adults living in industrial societies. All seven of the characteristics apply. First, insurance companies always charge novice drivers higher rates (characteristic 1), for good actuarial reasons. Even tiny errors at highway speed lead to disaster (2). Most drivers manage to pass through perilous situations unscathed, often marveling at their "luck" afterward (3). Drivers regularly listen to the radio, chat with passengers, and even talk on the phone without killing themselves (4), and they are able to drive strange vehicles with only a very short learning period (5). They cannot, however, fly an airplane (6). Almost all experienced drivers report having made the drive to work or home without any active memory traces of the journey (7).

In the modern world, we rely on expertise far more than most people realize. Indeed, it is the style of thinking that underpins most of our well-learned, complex activities. This kind of performance does not fit easily into standard accounts of long-term memory (LTM), short-term memory, or even working memory (WM). Cognitive psychologists who study expertise focus on the changing roles of WM and LTM in problem solutions. LTM consists of information stored and retained for periods longer than a few seconds. WM, on the other hand, consists of information held and processed in active attention and is very limited in capacity (by many orders of magnitude; see Baddeley, 2007). WM is effortful in the sense that one must constantly refresh its content or lose it. Yet WM is the locus of most active problem solving—hence the puzzle of expert performance. Experts appear to deploy information held in LTM with a rapidity and facility generally associated with WM. Neuroimaging studies of novices and experts reveal that tasks that engage the WM circuitry of novices shifts to LTM circuitry in experts (Guida, Gobet, Tardieu, & Nicholas, 2012). Clearly, experts are able to access task-relevant information in LTM very rapidly. The two leading models for how cognition does this are the *template theory* (Gobet, 1998; Gobet & Simon, 2000; Guida et al., 2012) and *long-term working memory* (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995; Ericsson et al., 2000). Both account for the phenomenon of expertise, but we find Ericsson's to be easier to adapt to the features of technical cognition.

Long-term Working Memory

Most of the information deployed in an expert performance is stored in long-term memory, of which there are several distinct varieties. Declarative memories are memories of "facts," often stored in the form of words but also in other forms of explicit imagery. In humans, the hippocampus plays a crucial role in the formation of declarative memories; individuals whose hippocampus is damaged cannot form new declarative memories. LTM also includes procedural memories, which consist of "how to" information that is largely sequential and based in the motor circuitry of the brain (Hecht et al., 2014). The hippocampus is not essential for storing procedural memories; instead, an extensive neural network that includes the frontal, parietal, and especially temporal lobes is paramount. Procedural memories are the predominant component of technical expertise (and perhaps the basis for all expertise, but that is an argument for another paper) and thus of particular relevance.

One clue to the organization of procedural memories comes from how they are learned. Thorough repetition is the key. A novice repeats the same sequence of motor actions again, and again, and again, until it becomes automatic. Think of a novice pianist learning a D-flat major scale. He or she learns the fingering very quickly, so why repeat the exercise hundreds or thousands of times? The answer is that rapid, accurate execution cannot rely on WM or even mental images of key locations. It must be automatic, with essentially no reliance on attentional resources. The only way to do this is to deploy an evolutionarily old system of learning—association. One discrete motor component of the sequence triggers the next directly because they have been linked by association. As the novice practices, he or she strengthens these associations and lengthens the chain of elements. At an expert level, the performer need only detect any small indication of key change to engage all of the appropriate scales and chords. This is a very reliable way to learn information, but it is very slow.

The second major cognitive component of expertise is WM, which in simple terms is an individual's ability to hold information in active attention *and* process it (Baddeley, 1986, 1993, 2001; Baddeley & Hitch, 1974). WM is a form of memory only in the sense of retaining information, but the length of time is brief, only a few seconds without active refreshing. This attentive ability was once termed "short-term memory," and its retentive capacity is measured by the number of bits of information one can hold for the short term (the number of digits in a sequence, for example). But, in the 1970s, Baddeley and Hitch (1974) realized that much more was going on in short-term memory than simple recall of facts. There is also a processing component of active manipulation of the information held in attention. These they termed the "central executive" because they consist of executive control mechanisms roughly equivalent to the executive functions of neuropsychology. An example of a test of WM capacity is the *N-back test*. For example, a participant is read a series of sentences and asked to remember the word that occurred three from the end in each of the sentences. The number of words remembered correctly is WM capacity (WMC). There is a processing component (counting back three from the end) and a memory component (holding the sentence in memory in order to count back and then retaining a list of these three-back words). As the label implies, executive functions are the higher level control and decision-making functions of active thinking. Three of these executive control mechanisms are response inhibition, task switching, and filtering distraction. The mammalian brain, for example, has evolved numerous automatic (prepotent) responses that enhance survival and reproductive success. One is fight or flight. But often such an automatic response impedes optimal problem solution, as when fleeing at the mere sight of another large animal would not be conducive to successful hunting. Thus, response inhibition has evolved as a component of executive control. Similarly, the ability to switch back and forth between tasks enhances the ability to solve multiple problems, and the ability to focus on a task and screen out distraction will facilitate efficient problem-solving. None of these three examples is simple information storage. All require active, effortful, manipulation. Not surprisingly, one's WM capacity correlates strongly with measures of general intelligence (Engle, Kane, & Tuholski, 1999). Interestingly, experts do not necessarily excel at WM problems, just as they do not necessarily excel in tests of general intelligence. Yes, experts with high WM capacity do tend to perform better (Engle, 2010; Engle & Kane, 2004; Engle et al., 1999), but high WM capacity does not produce expertise. The key to expertise appears to be rapid access to LTM.

Ericsson's model of expert cognition (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995; Ericsson et al., 2000) emphasizes two cognitive processes—cues and retrieval structures (Figure 2.1).

A cue is a memory trace that has been linked by association to a larger encoding of information held in LTM. A cue can be elicited by a *percept*, a visual or aural stimulus for example, or it can be retrieved from memory in response to a need. It is like a tab on a file. A retrieval structure is a larger, organized set of cues that, once actualized in WM, enables both rapid retrieval of a large amount of task-relevant information and also the rapid encoding of new information through its organized structure. Learning cues and retrieval structures is laborious because

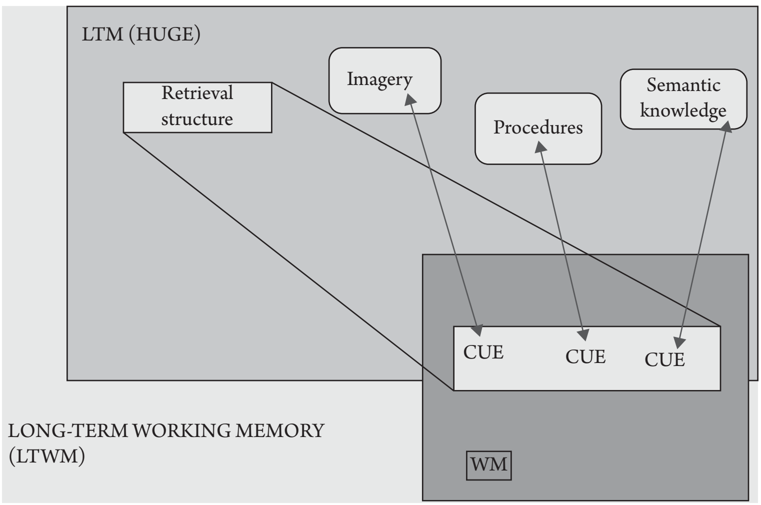

Figure 2.1 Graphic describing the relationships among working memory, long-term memory, and retrieval structures.

it relies on two old but effective mechanisms—chunking and chaining. In *chunking* several bits of information come to be linked together by association so that recalling one recalls them all. For example, if one wants to remember the number 17561827, an eight-digit number that exceeds normal WM capacity, one can remember instead two chunks—Mozart's birth year and Beethoven's death year, two facts already held in LTM—and recall the number easily. *Chaining* links chunks in series. The final element in one chunk acts as a trigger for the next chunk. One establishes chunks and chains by association, and this requires repetition. The more chunks and the longer the chains, the more repetitions are required. One cannot establish a retrieval structure through insight. Repetition is necessary. And yet, perhaps counterintuitively, a retrieval structure provides automatic flexibility in the face of changing conditions. The expert learns so many retrieval structures, each of which incorporates multiple options, that he or she has almost instant access to an appropriate response to any problem. This is especially evident in professional sport, where the performer must rely on automatic, well-learned responses and procedures. But it is also true for expert technical performance.

Imagine a blacksmith making an ornamental fleur-de-lis for a gate (the following is based on Keller & Keller [1996]). The smith works in a dynamic context in which he or she must modify the shape of iron stock that has been heated to a malleable state. How does the smith know when the appropriate temperature has been reached or when the iron has cooled too much to work? He or she could use some kind of external temperature gauge, but this would be awkward and slow. Instead, the smith relies on retrieval structures learned over years of apprenticeship in which color, radiant heat, sound, physical resistance, and muscle tensions act as cues that link to the appropriate response to the rapidly changing conditions. And what is especially interesting to students of human evolution is that almost none of the cues in these structures consists of declarative knowledge. Artisans, like athletes, are inarticulate about what they do. Words and symbols play little role and in fact add a layer of information that complicates the task, potentially impeding performance.

One unfortunate consequence of the largely nonverbal nature of technical expertise is that it is underappreciated as a form of thinking. The modern Information Age values facility in symbol use and manipulation. Individuals who are adept at solving word or mathematical problems are held in high esteem; individuals who detect flaws in plumbing systems and fix them are not, at least not as much. And yet far more of daily life relies on the expertise required for the latter than the creativity required for the former. For the vast majority of human evolution expertise was the principle cognitive system deployed in the day-to-day task of survival. It is also quite visible through analysis of the archaeological record.

Evolution of Expert Performance

Technical cognition almost certainly evolved through evolution of the neural resources on which it depends. The LTWM model incorporates two quite different neural networks—LTM and WM—each of which could have been under its own set of selective pressures. LTM capacity is arguably the more important of the two for successful technical cognition, especially the capacity for motor procedures. Any increase in long-term procedural memory capacity would have paid technical benefits. Increased capacity can be exploited in two ways in technical cognition: the size of procedural chunks and the number of procedural chunks. For motor procedures, size effectively means length of procedural chains; number means variety. Any increase in maximum length of a segment of motor procedure or in the variety of procedures available to an artisan will have payoffs in technical complexity. The neural network for procedural LTM is almost certainly the object manipulation network that evolved long ago in anthropoid primates (Hecht et al., 2014; Peeters, Rizzolatti, & Orban, 2013). Indeed, hominin technology must have been an elaboration of these resources; there are no other candidates. Modern technical expertise is, essentially, anthropoid expertise writ large.

Technical expertise also evolved via enhancements of WMC, but the benefits are not as obvious. Indeed, LTWM appears to be a solution to the problem of the very small storage capacity of WM. Expanding the number of items that can be actively held in attention from four to five will not suddenly enable an artisan to visualize an entire technical procedure. Access to LTM will always be necessary. But an increased WMC might enable the addition of other elements to the technical task. If activation of a retrieval structure does not exhaust WMC, then there is free capacity that can attend to other things. Such a situation often arises during especially well-learned procedures. Of course, day dreaming is a natural consequence that can lead to accident, but free capacity might also be used for innovation (Wynn & Coolidge, 2014). The neural substrate of WM is an extensive front-parietal network that is largely distinct from the object manipulation network (Coolidge & Wynn, 2005). Famously, when Stout et al. (Stout & Chaminade, 2007; Stout, Toth, Schick, & Chaminade, 2008) analyzed the neural activation pattern of basic percussion knapping there was no obvious activation of WM resources. Of course the knapper was an expert, and when experts perform a basic component of their expertise, the attentional resources of WM are not taxed. Interestingly, when Hecht and colleagues investigated the activation patterns associated with handaxe manufacture, some activation of WM resources were apparent, probably in the executive control component (Hecht et al., 2014).

Expertise in Human Evolution

The Palaeolithic archaeological record consists almost entirely of remains of lithic technology. Using the list of performance characteristics in the Expert Cognition Model (Table 2.1), as identified for the chess master and automobile driver, it is possible to analyze aspects of technological behavior as it appears in the archaeological record. We chose four technological expressions (hammer, simple-core, prepared-core, and composite) as examples to illustrate the application of the model because they span what we perceive to be some major

Table 2.1 **Assessment of four technologies using characteristics of expert performance**

Expert performance	*Hammer technology*	*Simple-core technology*	*Prepared-core technology*	*Composite technology*
1. Novices require years and thousands of repetitions to attain expertise	Yes	Yes	Yes	Yes
2. Experts perform with higher levels of accuracy	Yes	Yes	Yes	Yes
3. Experts perform rapid, in-depth problem assessment	Rapid, but probably not in-depth	Rapid with limited depth	Yes	Yes
4. Experts can be interrupted and can return to a task with little or no loss of information	No	Possibly	Yes	Yes
5. Experts learn new material rapidly	No	Yes	Yes	Yes
6. Expert performance is limited to narrow domains of activity	Yes	Yes	Yes	No
7. Experts respond mostly automatically, with little active attention	Yes	Yes	Yes	No

technological developments that can be traced archaeologically. These four technological expressions are, however, not intended to be exclusive. If the model is to be robust, any technological expression could in theory be analyzed in a similar way.

Expert Cognition for Hammer Technologies

Percussive technologies using hand-held hammers have now been documented for chimpanzees, cebus monkeys, and macaques (Carvalho, Cunha, Sousa, & Matsuzawa, 2008; Malaivijitnond, Lekprayoon, Tandavanittj, Panha, & Hamada, 2001;Visalberghi et al., 2007). As such, they constitute a kind of baseline technology for anthropoid primates and thus are the logical place to begin a comparison of expert technical systems. The Expert Cognition Model yields the following description, based on the best known example, that of chimpanzees:

1. By the age of 3, some infant chimpanzees start to use hammer stones to attempt cracking nuts. However, only after several years do they become efficient in reaching the goal; that is, retrieving food (the nut). Some infants who did not start the learning process at an early age and who did not perform continuous repetition of the task do not attain the skill at all (Inoue-Nakamura & Matsuzawa, 1997; Biro, Sousa, & Matsuzawa, 2006).
2. Adult chimps who have become proficient in nut cracking are able to process many nuts within a single feeding session, but those who have not become experts might spend much time at the task with only minor success (Boesch & Boesch, 1984*a*).
3. Experts are able to assess nut placement and rotate the nuts to enable successful cracking (Boesch, 1991). True, compared to the kinds of problem assessment necessary for driving a motor vehicle, such nut cracking may seem paltry. This is because the chunks of information are comparatively smaller. There are also many fewer chunks.
4. Because the chunks of procedural cognition are comparatively small, distraction is not a serious problem; starting over from the beginning requires only slightly more effort than picking up where one has left off. When needed, the activity is simply duplicated. The chain of activities necessary to prepare for successful nut cracking (i.e., collecting nuts and selecting anvil and hammer) is generally conducted in a sequence that ends with a nut cracking session. Although chimpanzees remember the locations of individual hammers, they don't seem to relocate the hammers independent of a feeding session (Boesch & Boesch, 1984*b*).
5. In the chimpanzee example, there is no learning of new materials/new information processing during the expert use of a hammer to crack a nut; the elements and their traits remain the same. For example, chimpanzees have

not been observed to apply hammer technology for retrieving other food sources.
6. It is clear that with this technology the domains of activity are very limited.
7. Expert chimpanzee nut crackers seem to respond mostly with little active attention to the task at hand.

Hammer percussive technology, as practiced by several nonhuman anthropoid primates, can thus be described as an expert system, suggesting that expertise as a procedural strategy is quite old in an evolutionary sense. Research using neural imaging technologies indicates that nonhuman primate percussive tool use is based in a distributed frontoparietal neural network known as the *object manipulation network* (Orban & Caruana, 2014). When one examines the descriptions of nonhuman primate percussive technology, as we just did, it is clear that this object manipulation network can easily be redescribed in terms of expert performance. It was almost certainly the neural network out of which expert cognition evolved. In other words, expert technical cognition as practiced by modern people, and perhaps all expert performance, has evolutionary roots extending back to the common ancestor of apes and monkeys. Hominins did not invent technical thinking; they merely elaborated a cognitive strategy that had been in place for millions of years.

With this baseline, it is possible to document subsequent developments in expert cognition. The basic organization of expertise did not change over the course of hominin evolution, but there was significant enhancement of components of the underlying cognition.

Expert Cognition for Simple-Core Technologies

Insights into simple-core technologies (which lack core preparation) come from two analytical techniques—experimental replication (e.g., Mahaney, 2015) and the refitting of cores (e.g., Delagnes & Roche, 2005). Work with experimental knappers readily confirms that simple-core technology is an expert task. Learning to remove even simple flakes takes time and repetition before the skill is mastered (characteristic 1). Indeed, one definition of an expert knapper is one who has been knapping for 10 years (Mahaney, 2015), precisely the number encountered in the literature on expertise. With practice, the knapper becomes increasingly accurate and efficient (2). For the accomplished knapper, assessment of materials and flake removal potential is rapid, but depth in problem-solving is limited because of the few potential problems that can be encountered during such a simple knapping strategy (3) (Mahaney, 2015). Whereas modern experimental knappers can be interrupted (4) during a simple knapping exercise, we do not know whether this was true for knappers in the deep past. However, the core refits from Lokalalei suggest, weakly, that the knapping occurred in single sessions; that is, one knapper started a core and continued until it was abandoned. Learning the properties of rocks for knapping and dealing with the shape and size differences in nodules intended for knapping probably happened rapidly for experienced knappers (5), but, similar to hammer technology, the performance domains during simple-core knapping is limited (6). Once a knapper has become proficient in flake removal, the knapping process becomes almost automatic (7).

However, knapping episodes are embedded in a more extended *chaîne opératoire* that included raw material acquisition and transport of nodules and hammers as well as the subsequent use of selected flakes for activities such as cutting or scraping (Haidle, 2012, 2014) and perhaps also the establishment of an appropriate social context (Stout, 2002), and this extended context may have required enhancements in cognition. For modern knappers, the "ecological" and "social" context is very different from that in play 3.3 million years ago (Harmand et al., 2015) and thus provides no appropriate analogs.

Here, we must digress briefly to air an internal disagreement. Wynn and Haidle actually disagree in their characterizations of the cognitive requirements of early hominin stone knapping. Wynn takes a conservative stance and argues that the *châines opératoires* required for Lomekwian (Harmand et al., 2015) and Oldowan knapping were comparable in complexity to those demonstrable for modern nonhuman primate tool use. Simple-core technologies are directly comparable to the hammer percussion on nuts practiced by chimpanzees and capuchins. A novice knapper quickly learns to examine a core for potential platforms, but this is little different from a chimpanzee positioning a nut appropriately on an anvil. There is nothing we know about the prehistoric context that would require that we invoke larger chunks of memory or more procedural chunks than used by chimpanzees or capuchins in their percussive activities. Evidence for extended transport distances (Wynn, Hernandez-Aguilar, Marchant, & McGrew, 2011), for example, requires only that raw material acquisition occurred within the context of normal foraging. This would not have required an ability to maintain attention through distraction (4), which is a WM component that would not have been engaged at such a large temporal scale but could have been incorporated into expert foraging systems. There were specific differences, to be sure, but nothing that would place these early knappers beyond the range of anthropoid object manipulation. Brewer and McGrew's (1990) documentation of a chimpanzee tool set is a case in point. In this example, a chimpanzee made and deployed a series of five different tools to break into and extract honey from the nest of stingless bees. Similarly, Byrne has described a complex sequence of manipulative actions used by mountain gorillas to process nettles (Byrne, Corp, & Byrne, 2001). Such multistep object processing easily matches the multistep procedures evident in early stone knapping. Thus, at the scale of knapping a core, there is nothing that clearly distinguished the cognition underpinning simple-core knapping from that of nonhuman primate percussive technology.

Haidle counters that Oldowan knappers, and arguably Lomekwian knappers as well, needed to monitor two separate objects when knapping—the hammer and the core—while maintaining fairly precise interobject orientations and also regulating force. Thus, the chunks in simple-core technologies are probably larger in the way that the knapper has to manage more variables (two objects) at once, whereas a chimpanzee has to manage one thing at one time: to put the nut on the anvil and then (subsequently) to pound with the hammer (without actively managing the nut in that moment). The same is true for the chimpanzee tool set to extract honey: the first fishing probe, the chisels, the bodkin, and the second fishing probe were independently used and abandoned "in a sequence" (Brewer & McGrew, 1990, p. 104) but were not applied simultaneously and in an effective chain, with one tool having an impact on another tool as in simple stone knapping. Furthermore, she argues that the early knappers regularly combined several activities (raw material and hammer acquisition, pounding/knapping [as in chimpanzees], use of flakes to work on something such as a carcass), each of them being an expert performance in itself. Identifying a good hammer stone or chert nodule and taking it along for hours while the hominin focused on other things such as feeding does not rely on "prospective memory" only, but also represents the ability to run more than one expert performance simultaneously. Furthermore, raw material acquisition decoupled from its immediate use, later knapping episodes, and probably also decoupled future use of the artifacts create effective chains not only within, but also between different expert performances. She concludes that these differences required level of complexity beyond anything known for modern nonhuman primates (Haidle, 2012). However, despite this modest disagreement about degree of difference, Wynn and Haidle agree that nonhuman primate tool use and early hominin stone knapping are clear examples of expertise and that all can be explained using the organizational resources of chunking and chaining.

Does our description, and disagreement, imply that no evolution in cognition accompanied the advent of lithic technology? After all, most authorities on early hominin stone knapping continue to describe it as an evolutionary Rubicon requiring complex cognition (Schick & Toth, 2006). The expert performance model provides a framework with which to compare early hominin knapping to nonhuman percussive technology. The first conclusion is that no qualitative difference is apparent. Resources of long-term procedural cognition are sufficient to account for capuchins cracking open nuts and for hominins at Lokalalei producing and using flakes. No "complex hierarchies" are required in either case. Both are easily within the WM capacities of modern apes. The Lokalalei knappers may have used *longer* procedural chains and perhaps had *more* procedural chains. This argues for a modest increase in LTM capacity. But we urge caution. There are examples of chimpanzees using procedural chains equal to or longer than those documented at Lokalalei. Thus, our conclusion is not that capuchin percussive technology and Lomekwian/Oldowan percussive technology are indistinguishable, only that the difference was not dramatic and did not require a qualitative jump in the cognitive resources of the anthropoid object manipulation network.

Expert Cognition for Prepared-Core Technologies

In prepared-core techniques, the knapper prepares and manages a core in such a way that products (flakes or blades) of predetermined size and shape can ultimately be produced. Examples of prepared-core technologies include the Levallois technique and prismatic core technique, as well less common techniques such as Victoria West and Tachenghit. The basic structure of expert performance for prepared-core technology was the same as that for simple-core technology (Table 2.1). However, the nature of core preparation and monitoring require significant developments in both LTM and WM.

With core-preparation technology, the expert is faced with a greater range of problems than encountered in knapping simple-cores. Each of these problems must cue a chunk of information held in LTM, and the nature of many of the problems requires larger chunks of information in the solution. From the analyst's perspective, these longer chains of information can be parsed into units and subunits (i.e., a hierarchy). However, the hierarchical organization may not be required for either learning *or* execution; it is important not to mistake our fondness for hierarchies for actual cognitive structures. Chunking and chaining can yield "complex" sequences without recourse to a hierarchical generator of some kind. Indeed, expertise requires years to attain precisely because the underlying cognitive mechanisms are simple (chunking) and linear (chaining). Nevertheless, the number of routines and length of procedural chains required in prepared-core technologies would have required an increase in long-term procedural memory capacity well beyond the range of simpler percussive technologies.

Prepared-core technologies also require deeper rapid problem assessment (characteristics 3 and 5). Each problem requires an immediate solution, yet the knapper has to hold in mind what he or she ultimately intends (a goal that might still be several steps removed from the current situation—similar to our chess master) by following the process. In the well-published refit example of Marjorie's core (Schlanger, 1996), the knapper clearly attended to consequences that current knapping decisions had for future phases of reduction. We therefore see an increase in the depth of problem-solving capacity compared to the previously analyzed technologies, and this requires not only increases in size and number of informational chunks, but also an increase in WMC. For one, there are just more variables to hold in attention—primarily variables related to core management—and attentional capacity is one of the limiting features of WM. Monitoring a prepared-cored also requires rapid task switching and the ability to suppress a salient response (an immediate knapping problem such as a hinge removal) in order to maximize a solution further along in the preparation procedure. These are features of the cognitive control components of WM. Experimental knapping also suggests that these cognitive control mechanisms are an important factor in teaching. Experimental knappers have been observed to engage in conversation while knapping or stop to teach an apprentice, yet continue to produce the required flakes/blades without mishap.

Finally, prepared-core reduction hints at an important role for semantic LTM. In the Marjorie's core reduction, the knapper followed a kind of rule: "after successfully striking off a large flake, rotate the core 90 degrees so that a current lateral convexity becomes the distal convexity for the next phase" (Wynn & Coolidge, 2010). Such a conventional rule almost certainly existed in the mind of the knapper as a chunk of semantic information. It was also probably verbal and was probably learned verbally from a teacher (see, e.g., Högberg, Gärdenfors, & Larsson, 2015). Many archaeologists have suggested that prepared-core technology required active teaching. Our current model takes a more modest stance. Prepared-core technology required semantic LTM as well as procedural long-term memories. Active instruction would have been the most efficient way to learn this semantic knowledge.

In sum, prepared-core technology falls well outside the cognitive range of the basic primate and early hominin object manipulation network. It required marked increases in long-term and working capacity and probably a semantic component to LTM that is unknown for nonhuman technology and not apparent in simple-core technology. Prepared-core techniques began to appear as early as 500,000 years ago, but even this seemingly early date falls almost 3 million years after the known advent of stone knapping and thus represents a comparatively late development in technical evolution.

Expert Cognition for Composite Technologies

A composite tool is one that has two or more components combined together to act as a single unit (Ambrose, 2010; Barham, 2013; Haidle et al., 2015). For example, Neandertals used birch pitch to haft Levallois points (manufactured with a prepared-core technique) onto shafts to function as stone-tipped spears. Compound technology is a subcategory of composite technology that employs mixtures of materials such as certain glues and adhesives. Breakage patterns of the points, along with actual residue of birch bark pitch, confirm the composite technology as early as 200,000 years ago (Mazza et al., 2006; Rots, Van Peer, & Vermeersch, 2011). Compound materials like adhesives and paint have been used in the southern African MSA starting at least around 65,000 years ago (d´Errico et al., 2012; Villa et al., 2015; Wadley, 2010).

Compared to prepared-core technologies, our analysis reveals that expert performance characteristics for compound and composite technologies are similar for the first five categories in our model. However, we suggest differences in characteristics 6 and 7. The performances associated with the previously discussed technologies are all limited to narrow domains of activity. For example, they are limited to the use of a single tool category (hammer) applied to a single object (nut or core), and although some properties of the chosen materials might vary, the materials themselves remain within a narrow range. But, with compound and composite tools there is a marked broadening of performance domains. To produce a composite/compound technology, whether it be a compound adhesive (Wadley, 2010, 2013) or a stone-tipped spear (Coolidge et al., 2016; Lombard & Haidle, 2012), the artisan has to be proficient in a wide range of manufacturing processes and understand the properties of the various materials needed for each to complete the technology successfully. This type of technology thus requires expertise in multiple fields and, by extension, retrieval structures with more cues and a greater variety of cues.

Because this is an expert system, some procedures become automatic, requiring little attention during performance. These would include activities such as collecting all the necessary materials, knapping a stone point, or shaping of a haft/shaft. The activity of combining the different elements can, however, hardly be executed effectively without paying active attention to each element and its changing properties during the process of combination. For example, during the process of fixing a stone tip to a shaft using an adhesive and binding materials, the artisan has to pay simultaneous attention to the properties and position of the tip as well as to those of the shaft and how they could best fit together. He or she needs to carefully manipulate the binding material and/or adhesive so that the arrangement of tip and shaft remains stable during binding.

During her experimentation with compound, ochre-loaded adhesives, Lyn Wadley (2010, p. S115) also noted the following: "There is no recipe that can be followed; making these glues is not like baking a cake. The technique is not routine; it entails evaluating the qualities of the ingredients and adjusting their quantities accordingly. It requires complete, undivided attention." Similar to the Kellers' (1996) description of cognition of blacksmithing, some of the discrete phases of compound glue manufacture are linked to one another via visual and tactile cues. For example, the grinding of ochre using a grinding stone is a chunk of visual and tactile cues. The step terminates when the artisan perceives, via visual and tactile percepts, that the ochre powder is sufficiently fine and of appropriate quantity. This terminal condition elicits a shift in focus, now requiring the glue maker to interact with the other ingredient, the resin, ultimately eliciting the next step of adding ochre to resin (see Lombard & Haidle, 2012, for discussion and illustration of this activity). Up to the point where the actual mixing takes place, the entire sequence of steps can be learned and executed using the cognitive mechanisms of chunking and chaining. The expert craftsman need not pay much attention because the retrieval structure delivers the steps automatically, guided by the occasional percept. But it is not a rote sequence. Variation in percepts (e.g., flaws in the ochre during grinding) instantly elicit alternative procedures held in LTM. This is a classic example of expertise in action. Flexibility is built into expertise, which is why it is such an effective strategy for day-to-day problem-solving.

From Wadley's experiments (e.g., Bradfield, Wadley, & Lombard, 2015), we see that the production of the mixture itself, however, requires the full attention of the glue maker. Small disparities in any of the variables may lead to an unsuccessful adhesive. For example, careful attention must be paid throughout the mixing process to aspects such as texture and viscosity. There is no pre-set formula because the moisture content of resin is different for each tree and will vary depending on the time it was exposed before collection, the thickness of the deposit, and the season during which it was collected (e.g., Wadley, 2005). Ochre powders might also vary in quality and crystallography, which could affect their binding properties with the resin. In addition, environmental circumstances at the time of mixing, such as moisture, temperature, and wind, will further impact on the quality of the mixture and whether it will dry successfully once applied. "Achieving the correct texture and viscosity by adding ochre is thus different for each batch of glue mixed" (Wadley, 2005, p. 598). After the successful production, the glue is then used to compose a new composite artifact consisting of different materials, textures, shapes, weights, and sizes. These processes of preparation and assembly (even though they may only take a short while to complete or consist of only a few steps) rely on the attentional resources of WM; the task switching and response inhibition of the cognitive control elements of WM are heavily engaged. Arguably, production of such composite technologies required an increase in WMC compared to simple one-component tools. Effective chunking and chaining alone can no longer guarantee success, though they certainly remain important. The artisan needs the ability to hold information about a range of materials, their traits, and the various effects they might have upon each other in active attention, continuously process the information, and adapt accordingly to achieve a successful composite technology.

Evolution of Expertise

Based on current knowledge of the archaeological record and the outcomes of our analyses, we suggest that hammer technologies predate simple-core technologies, of which we see the earliest examples by about 3.3 million years ago (Harmand et al., 2015). Directly comparing hammer technologies with simple-core technologies revealed only subtle changes in expert cognitive performance.

There was a quantitative increase in the size of the chunks and the number of chunks. Prepared-core technologies were well established by at least 300,000 years ago, but might have been in use as early as 500,000–800,000 years ago (e.g., Tryon, McBrearty, & Texier, 2005; Wilkins, Pollarolo, & Kuman, 2010). With these technologies, the full range of expert cognition can be traced (Table 2.1). Also, aspects regarding in-depth problem solving and information management during interruption, which are not obvious in simple-core technologies, now seem present. Direct evidence for composite technologies in the form of use traces and birch tar on stone tools dates to about 200,000 years ago (Mazza et al., 2006; Rots et al., 2011), earlier hafting interpretations are being debated. Thus, 200,000 years ago can be accepted as a parsimonious age for composite tools. Also, and important to keep in mind, is that the Expert Cognition Model is not dependent on "species," "age," or "origin": it is able to assess expertise performance of technological expressions regardless of where and when they appear or by whom they were produced. That being said, it is with composite technologies that our analysis reveals another potential shift in the evolution of cognition. It seems as though an increase in WMC was required for the successful composition of different materials into a new technological unit, and even more additional cognitive resources were required for composite technologies.

As a cognitive strategy, expertise is arguably old in an evolutionary sense. Chunking, chaining, and use of cues are old learning mechanisms in the sense of being true of mammalian learning in general. Elements of chunking and chaining are apparent in the lithic reduction sequences of some of the earliest known stone tools (Delagnes & Roche, 2005; Harmand et al., 2015; Semaw et al., 2003), and cue use is also a component of nonhuman primate technology. So has nothing evolved? The advantage of applying an explicit cognitive model becomes apparent in answering this seemingly simple question. Yes, something clearly evolved, but it was not what many archaeologists have supposed. There was not much increase in "hierarchical complexity," for example. This is a favorite of many common-sense–based discussions of technical cognition (Delagnes & Roche, 2005). After all, the *chaînes opératoires* of later time periods often present more levels of nesting than earlier ones. But a *chaînes opératoire* is *not* a cognitive model; it is instead a description imposed on a sequential activity. Analysts are quite fond of hierarchies, but most are creations of the analyst, not inherent components of the actual cognitive system. If technical cognition consisted of nicely organized tree structures, they would be much easier to learn.

Instead, expertise requires thousands of repetitions because the underlying organization is linear and sequential and must be learned laboriously through chunking and chaining. This is true today and was true 3.3 million years ago with the earliest stone tools. Thus, the primary evolutionary development in expertise was an increase in procedural LTM capacity. Increase in LTM capacity, especially for procedural memories, would have enabled retrieval structures that contained more information and, perhaps more important for flexibility, more retrieval structures.

Nor does language appear to have played a central role in the evolution of expertise. Technical retrieval structures consist largely of nonverbal, procedural routines. Even the cues that call up retrieval structures are largely visual and kinesthetic. Words can and do act as cues (e.g., "hex wrench"), but they are not primary and are perhaps even superfluous. Skilled craftsmen are not known for the richness of their vocabularies and often struggle to verbalize what it is they are doing. This point bears emphasis. Palaeolithic archaeologists tend to privilege language when addressing cognitive questions for reasons linked more to the recent history of social science than to the archaeological record itself. Language was not the only important cognitive system to have evolved over the course of human evolution, and misplaced obsession with it has meant that other cognitive domains, such expertise, have been slighted or ignored entirely.

Conclusion

From our simple analysis, it is evident that expertise as a cognitive strategy is old in an evolutionary sense, with its roots in the anthropoid object manipulation neural network. Components of expertise have certainly evolved, and the archaeological record provides some evidence for this. Early simple-core and Lomekwian technology required expertise that was still very ape-like, with only modest developments in the size of chunks, sequencing of chunks, and extension of time depth of chunks, with perhaps also prospective memory in raw material transport. Prepared-core technologies, on the other hand, present expert performance characteristics similar to those observed in modern-day chess masters. In particular, such technologies require much larger chunks of information, and many more chunks of technical information stored in LTM. In addition, they required rapid task switching and the ability to ignore distraction, both components of the cognitive control mechanisms of WM. But it is important to emphasize that expertise is a combined cognitive system, with components of both long-term and working memory. The evolution of expertise as a coherent cognitive strategy was one of the trajectories that powered hominin evolutionary success. Indeed, it was not until comparatively late in technological evolution that the archaeological record provides examples of compound and composite technologies that required anything beyond expertise to produce and maintain. And even though it arguably evolved in support of tool use and tool-making, expertise became the basis for other activities; in the modern world, expert systems abound, including music, games, and sport.

But expertise is not the only cognitive system of importance, even in technology. We must also ask how technical expertise was embedded within a larger technical system, and the answer reveals important information. Let us assume for purposes of discussion that one of the prepared-core flakes was destined to become part of a composite tool such as a point hafted onto a thrusting spear (only one of many options for such a flake). Two of us have argued that such a technical system required an "ability to combine several fully separate elements to create a new concept—composition" (Lombard & Haidle, 2012 p. 258). In other words, there were other discrete modules in addition to the knapping, and these modules needed to be coordinated and combined to produce a stone-tipped spear. The other two of us have described such a hafted spear point as "the first engineering design in the history of technology" (Wynn & Coolidge, 2012, p. 55). Barham (2013) refers to composite technologies as the first industrial revolution, and our expert cognition analysis now reveals that with composite technologies somewhat "more than expertise" might be necessary (at least sometimes)—perhaps an increase in WMC. But, again, such technologies emerged only late in hominin evolution.

Increases in WMC would also have had an effect on expertise, primarily through the number of cues that could be accessed in attention. But perhaps the primary consequence of increasing WMC would have been increasing "free attention" space during execution of retrieval structures. Well-learned retrieval structures access LTM with minimal demands on attention, allowing the mind to wander, day dream, and, with proper motivation, innovate (Wynn & Coolidge, 2014). Innovation is not an inherent feature of expertise, but it is enabled by WM.

The long millennia during which lithic technology changed little and slowly attests to the dominance of expertise as a cognitive strategy in technical thinking. It was, and is, very effective for complex, everyday tasks. We rely on it today more than most people realize, and it continues to power some of our most esteemed accomplishments in artist performance, sport, and craft production. But it evolved long ago, in conditions quite different from the modern world.

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3

Toward a Richer Theoretical Scaffolding for Interpreting Archaeological Evidence Concerning Cognitive Evolution

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Introduction

Ever since Neandertal skulls were found in Engis Caves, the questions that have perhaps attracted the greatest interest concerned how much like us such archaic species might have been in their bodies, minds, or behavior. Whereas an early answer was that Neandertal cognition was different from ours, it was based on inferences from the bones and the artifacts found with them (for an authoritative history of early studies of Neanderthals, see Trinkaus & Shipman, 1993). Across the 19th and early 20th centuries, schemes were developed to classify the artifacts (e.g., Lartet & Christy, 1875). By the early 20th century, it was generally agreed that Neandertals with Mousterian flake industries were replaced by Cro-Magnons with Upper Palaeolithic blade industries (e.g., Obermaier, 1925). The Upper Palaeolithic was also marked out by the presence of art forms, symbols, beads, and worked bone tools. This heuristic empirical association was all that grounded the inference that minds like our own were in existence in the Upper Palaeolithic, with the assumption that their cognition was more "advanced" than their archaic precursors.

Over much of the 20th century, classificatory schemes for the assignment of artifacts underwent refinement, but the basic dichotomy between modern humans and their precursors in any part of the world was rarely questioned until the end of that century. Subsequently, there have been detailed debates concerning the use of physical traces as evidence about the brains, minds, environments, and social groupings of those who left them (e.g., Davidson & Noble, 1989; Donald, 1991; Dunbar, 1993; Mithen, 1994; Wynn, 1979).

Central to these debates has been the extent of archaeologists' engagement in interdisciplinary work that can potentially advance interpretations of material evidence. A 21st-century archaeologist can call upon numerous techniques including carbon dating, DNA analysis, species identification of flora and fauna, analyses of diseases, causes of death, and the geographic origins of individuals from their skeletal remains. Recent inferences about the advent of cooking have even made reference to energetics (Carmody & Wrangham, 2009) and to analyses of dental calculus (Hardy et al., 2012), while detailed chemical analysis and experimental archaeology have supported inferences about the development of compound adhesives (Wadley, Hodgskiss, & Grant, 2009). Neuroscience and psychology also have much to offer in scaffolding lines of enquiry about the properties of minds and behavior.

Many of these developments involve the augmentation of descriptive theory by some explanatory components. Attempts at explanatory theory, while providing more or less coherent narratives, have tended to follow isolated threads of inference based upon specific neural, mental, or behavioral capabilities. Because change is usually multifaceted, seminal contributions have continued to rely on heuristic lists of criteria observed in the record to infer candidate properties of mind (e.g., McBrearty & Brooks, 2000). Against this background, there is a pressing need for more sophisticated schemas of inference that can not only accommodate multiple perspectives (Byrne et al., 2004) but that also can make proper use of theory from the behavioral and neurosciences to support inferences from and about the archaeological record (e.g., Barnard, 2010; Garofoli & Haidle, 2014; Wynn & Coolidge, 2010).

In this chapter, we advocate an approach in which inferences are grounded on an integrated set of macro-theories. We have specified elsewhere how such macro-theories can be applied to our own use of modern technologies (Barnard, May, Duke, & Duce, 2000). Here, we apply the same approach to the scaffolding of arguments about the evolutionary progression of architectures of mind across the hominin line. We focus particular attention on how our hypothesized mental architectures for archaic species of *Homo* differs from our own mental architecture and how such differences can shape and constrain the interpretation of physical traces in the archaeological record.

Layers, Interconnectedness, and Threads

Architectures of mind relate to processes that build and modify mental states. The currency for analyzing the *behavior* of minds is therefore denominated in units of "information." We can only know about this behavior indirectly by observing its effects in behavioral architectures (actions—including vocal ones—of animate agents, objects, and environs) or by measuring the electrochemical behavior of neural architectures. We must accordingly be in a position to make inferential connections within and among at least these three layers (neural, mental, or behavioral) or levels of explanation.

Figure 3.1 depicts the three system layers. In each layer an architecture (A) is decomposed into basic units (Bs) that are themselves decomposed into constituents (Cs). Of course, identifying the parts of a system is insufficient to understand how it actually behaves. To approach a well-formed theory, we also need to specify how the parts are configured to interact one with another, what capabilities those parts individually exhibit, what requirements need to be met for those capabilities to work, and how the system is dynamically controlled and coordinated (see Barnard et al., 2000). We could add cellular or molecular architectures or higher order social systems respectively to the left and right flanks of Figure 3.1. Importantly, this scheme is not reductionist in a classic sense—the parts are not decomposed in a single hierarchy. We need to make inferential connections between layers because the systems' behavioral patterns are *qualitatively different*. In one case, we need to explain electrochemical activity, in another we need to explain how changes in information states occur in the mind, and in the third we need to explain actions in the world. No amount of neural theory will explain why verbs occur in one pattern in Arrernte and a different pattern in English; that requires an understanding of mental architecture and how it is constrained by the behavioral architectures and cultural landscape it inhabits over a lifetime.

The system-level characterization is important. In a tool-making architecture, the collection of Bs might include an agent instructor, an agent novice, a core,

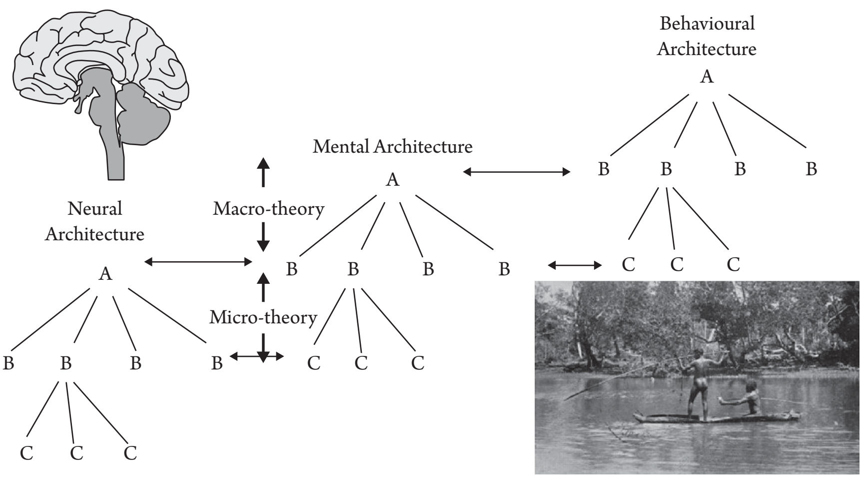

Figure 3.1 Layering of neural, mental, and behavioral architectures. Image credit: Two Aboriginal men spear fishing from a bark canoe, Port Macquarie, New South Wales, ca. 1925 by Thomas Dick, National Library of Australia, nla.pic-vn6100988.

and soft and hard hammers, as well as aspects of the environmental setting. In this case, we may be building a theory of tool-making instruction. A different account of behavior and communication patterns would occur if the behavioral architecture in focus were composed of two expert agents as opposed to an expert and a novice. A novice may lack attributes of mental capabilities that encompass many "basic units" of mental architecture from perception through thought and memories to the refined control of manipulation. To grasp this overall pattern, we need a macro-theory of mental architecture, not just micro-theories of the individual basic units such as perception, thought, memory, or manipulation.

Figure 3.1 marks this distinction between macro- and micro-theory. In seeking to approach the precision of formulation of the physical sciences, theorizing in psychology tends to focus on tractability. This criterion encourages micro-theories of limited scope that are applicable within a restricted task domain such as perception, language use, or problem-solving. Unfortunately, most micro-theories in psychology do not seamlessly link up in a way that would help us explain tool manufacture and use in all their facets. Although it is widely acknowledged that all our micro-theories *should be coherently interlinked* in principle as well as in practice, what is required to achieve this macroscopic integration is, more often than not, the elephant in the theoretical room. Macro-theories should specify *all the main components* (Bs) as well as how they interact while allowing micro-theories to be specified in increasing detail using compatible concepts and terminology.

In the case of mental architecture, we currently have little in the way of agreement about how best to decompose the mind, let alone how to model its behavior. There can be somewhat greater agreement on basic units of neural architectures or basic units of behavioral architectures but, even where this holds, we still fall far short of knowing the precise capabilities of those basic units, what requirement must be met for them to be used, or how these complex systems are dynamically controlled and coordinated. In short, we do not have mature macro-theories for any of the system layers we need to be in a position to address. Against this background, the layering in Figure 3.1 can help us to do two things: it can help us analyze current practices in inferring links marked by horizontal arrows between neural, mental, and behavioral systems; and it can be used to frame and guide new theories with improved scaffolding for inferences in cognitive archaeology.

In relation to current practice, there is no shortage of ideas about the evolution of mind. Many of these ideas take a point of departure within mental architecture or neural architecture and then build a linear narrative thread to some consequence in behavioral architecture and the traces they leave behind indicative of, for example, tool use, language use, or even social groupings. Examples of starting points involving a change in a specific component of mental architecture include perception (Davidson & Noble, 1989; Wynn, 1979), motor control (Donald, 1991), gesture making (Corballis, 2002), planning or abstract thought (Noble & Davidson, 1991), and enhanced working memory (Coolidge & Wynn, 2005). Ideas from physical systems include foci on DNA mechanisms (Crow, 1995), alterations to neural connections (Deacon, 2007), or changes in brain morphology as inferred from endocasts (e.g., Bruner, 2010). Yet others focus their explanatory narrative within the realm of material engagement in situated behavioral architectures (e.g., Malafouris, 2013). Several such approaches are illustrated in this volume. In principle, Figure 3.1 provides a schema to describe how any given argument threads its way within and across layers, to identify similarities and differences between accounts and to assess how well their arguments adequately integrate what is known within a system layer or how well connections across the layers are made (again, see Barnard, 2010).

In relation to the framing and scaffolding of new theoretical formulations, Figure 3.1 represents our strong assertion that you cannot predict from neural architecture (or indeed any system at an even finer grain of analysis such as DNA) the behavioral or social architectures that leave their traces in the archaeological record. Additionally, because the basic components within mental architecture are richly interconnected, the making of connections from constituents of mental architecture to behavioral architecture is also fraught with dangers. Pertinent macro-theoretic assumptions will either be absent or implicit. Although the problems of scaffolding adequate inferences within and among layers should not be underestimated, we can identify some criteria that may assist in the process. Figure 3.1 suggests that the drawing of connections between mental and behavioral architecture can most usefully be bridged using macro-theories of mind rather than many micro-theories. It is the properties of the overall mind in all its richness and constraints that impart the capabilities of individual minds or of classes of mind into those behavioral architectures that leave their physical traces in the record.

A Family of Macro-Theories of Mind

Barnard et al. (Barnard, Duke, Byrne, & Davidson, 2007) proposed a trajectory for cognitive evolution across the hominin line. This takes as its point of departure the mind of a basic mammal, lacking any form of sophisticated cognition, in which a single "multimodal" subsystem integrates over the products of sensory mechanisms to control action selection. Rather like cell division, the core argument is that the multimodal component underwent five successive subdivisions to yield an architecture with nine subsystems that is sufficiently rich to account for our mental capabilities. Obviously, the architectures at the beginning and end of the trajectory can be anchored and validated against laboratory and field evidence from modern-day animal and human psychology. Great apes, with more advanced spatial-praxic cognitions, provide an intermediate anchor point for validating key assumptions underpinning the proposed progression.

At each transition along the trajectory new mental capabilities emerge out of reorganizations of underlying neural systems. We can draw inferences about the floor and ceiling mental capabilities of the architectures for hominin minds by considering how their "basic units" of mind are configured. From that, we can go on to examine what that implies for how they would behave across behavioral architectures for tool making, provisioning, and so on. The arguments presented here will rely only on three macro-theoretic properties of whole architectures: (a) specialization of processing domains, (b) the depth of abstraction they support (a property related to the kinds of meaning systems controlling actions), and (c) the extent to which they can mentally do more than one thing at a time (a property known as *concurrency*). We do not need to draw on details of micro-theories and hence both the intra- and interlayer links conform to the requirements implied by the schema of Figure 3.1.

Figure 3.2 shows our proposed four-subsystem mental architecture (Barnard et al., 2007). The largest circle contains all the "basic units" of mind, with pertinent forms of material engagement with stuff in the world indexed outside this circle. In the upper area, three sensory subsystems are shown (visual, body-state, and acoustic) with a single multimodal subsystem below them. Naturally, each of these subsystems has constituent processes (the C's of Figures 3.1 and 3.2), detailed in other papers. Here, it is sufficient to note that this particular theory holds that each subsystem has, in addition to processes, its own memory and a dynamic "image" of the patterning of information over time. The information in that image can be attended to selectively, and its content is the basis of what can be experienced as sights, sounds, and bodily sensations, whereas the content of the multimodal image would be experienced as a more abstract sense or "feeling."

The architecture of Figure 3.2 is a macro-theory in the sense that the basic units and their constituents are a comprehensive breakdown of the major system components and the paths over which they interact. The associated body of theory provides the skeleton of what the systems encode, store, and process and how it is accomplished (e.g., Barnard, 1985; Barnard et al., 2000). The micro-theoretic "flesh" of specific patterns of information that are encountered, stored in memory, and processed through to the next stage need to be modeled for specific task domains and have been for several tasks including attention (e.g., see Su, Bowman, & Barnard, 2011).

Were the basic mammal to be one of Pavlov's dogs, for example, the sights, sounds, salivary responses, and bodily correlates of pain or food reward would create images and patterns in the three individual sensory subsystems. These patterns are first-order abstractions of sense data. However, when processed

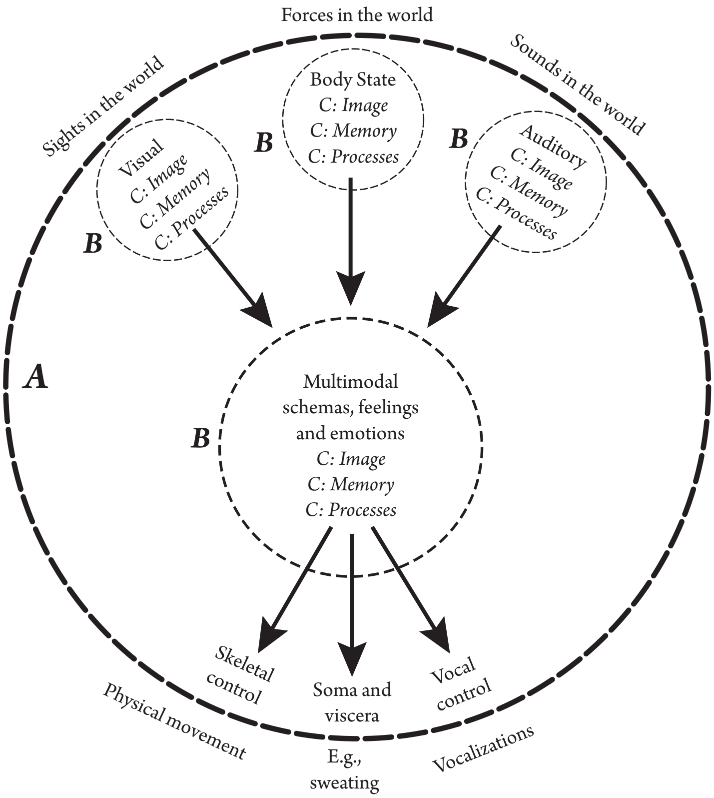

Figure 3.2 A mental architecture (A) incorporating four subsystems (Bs). Each subsystem has three classes of components (Cs): an image that supports phenomenological awareness, a memory, and processes that pass information either to another subsystem or to directly control bodily responses.

through to the multimodal subsystem, deeper abstractions (or schemata) would be created and preserved in its memory system about what patterns of sensations go with what feelings and emotions and what actions should go with what schemas. They are the substrate for classic properties in learning theory—*generalization* (reacting to similar states and contexts in similar ways) and *differentiation* (reacting to different things in appropriately different ways). Importantly, the macro-theory determines that these patterns are *second-order* abstractions, which we will illustrate later (for more technical details, see Barnard et al., 2007). In moment-to-moment functioning, much is going on at one and the same time within each subsystem, with processes making images, storing and accessing memory records of salient patterns, and sending information to other parts of the system. Note, however, that the overall flow of information is *unidirectional*, with the products of sensory processing flowing to a multimodal stage and the products of the multimodal stage directly controlling various musculatures. Given restrictions on attention, this is a basic, low-concurrency, "one-track" mind.

Because we shall be focusing on the final transition to a nine-subsystem architecture, Figure 3.3 shows its immediate precursor, an eight-subsystem architecture. Notice first that the four subsystems of our core mammal (Figure 3.1) are still there, integrating the products of sensory flows selecting actions, but, for simplicity, we have dropped the internal components of each subsystem. There are also a number of vital differences in how the subsystems are configured to interact and what types of information they process. The multimodal subsystem of this architecture receives inputs not just from a sensory subsystem but also from two others, specialized to process images in the mind of spatial praxis and phonology. It also sends information to these same two subsystems and additionally to two further subsystems specialized to control bimanual manipulation and vocal articulation. In terms of our three macro-theoretic properties, there are four new specialized domains of processing, greater potential for concurrent processing of spatial-praxic and phonological images, and, since there can now be three stages of processing prior to multimodal integration (there are two new indirect routes via spatial-praxic and phonological routings), action selection can be determined, in part, by some third-order abstractions.

We shall now briefly summarize the sequence of additions (indexed in Figure 3.3: B5, B6, B7, B8) proposed by Barnard et al. (2007). The first segment of the overall trajectory involves the development of more advanced skills in "spatial-praxis" and its internal representation. First, some precursor species of primate is presumed to have evolved intricate manual dexterity in the context of the wider control of bodily musculatures—such as reconfigurations of balance required when reaching to twist off a fruit. The product of this differentiation would have been a new daughter subsystem specialized for the control of manipulation (Figure 3.3: B5).

Importantly, the temporal patterning of skeletal reconfigurations controlled by the manipulatory subsystem would be sensed within the body-state subsystem and their first-order patterns, or derivatives, sent on to the multimodal subsystem. In parallel, of course, the primate would be "seeing" the action, and the first-order derivative abstractions of the dynamic changes in visual patterning would also be sent to the multimodal subsystem. Here, the underlying neural networks would be able to correlate and abstract properties of the changes that were shared by both visual dynamics and body state dynamics—abstract invariants relating to, for example, twisting, inverting, timing, size reduction, and so on. These abstractions would initially form the seeds of a new "spatial-praxic" coding system. Once a fully differentiated coding system stabilizes, another daughter subsystem would emerge (Figure 3.3: B6). The technical details of the differentiation are given in Barnard et al. (2007). Of note here is the fact that the new sixth subsystem intermediates among vision, effector control, and

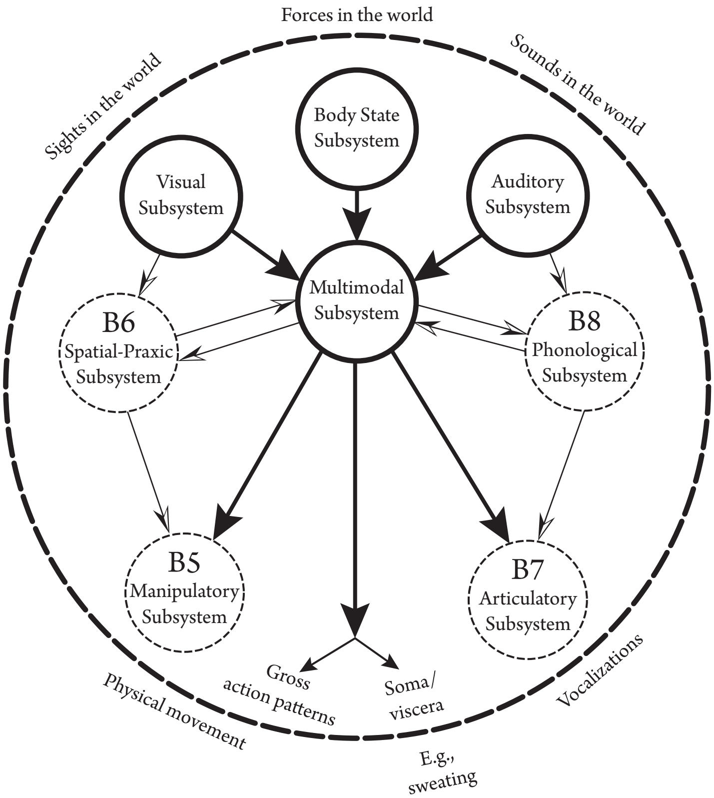

Figure 3.3 An eight-subsystem architecture notating the sequence in which new subsystems have been added. In this diagram, the evolutionary signature of the core mammalian architecture is shown in bold, with the new processing potential indexed via lighter borders and half-shaded arrowheads. The image, memory, and process constituents that make up each subsystem have been omitted for simplicity.

multimodal synthesis. It represents a gateway for the interpretation of visual patterns over time as well as their implementation as actions in the world. Spatial-praxic encodings represent the second-order abstractions that were originally embedded in less differentiated form with the original multimodal subsystem. They can usefully be thought of as something akin to deeper "structural descriptions" of changes in visual states and their realization in action.

Three critical capabilities underpinning mental advance emerge at this point. First, there is a new level of abstraction. The multimodal subsystem receives information via a new indirect route that has undergone *two* preceding types of analysis. On this indirect route, the sensory analysis is followed by a more abstract spatial-praxic analysis *before* being passed to the multimodal subsystem. Whereas the four-subsystem architecture had just two levels of analysis, the multimodal component of a six-subsystem architecture would be able to compute *a third level of abstraction* that relates actions in physical space to other multimodal elements.

Second, the four-subsystem architecture involved unidirectional traffic from sensation to action control. The six-subsystem architecture now supports an internal cycle—a reciprocal exchange, or *mental dialogue*, between the processing of multimodal images and the new spatial-praxic ones. This mental architecture has a form of visual imagery that can occur concurrently with the control of overt action and supports "reordering" of action elements. This architecture can "think" spatially while doing. If you, the reader, imagine rotating the mental image of a cup in your mind's eye, then that provides a sense of the type of imagery that a six-subsystem architecture can effect.

Third, the now deeper derivatives of abstract structural descriptions of actions in space (i.e., movement phrases) can be linked with emotion in the multimodal subsystem rather than just with similarities in movement based on first-order sensations. This architecture can, in principle, have "feelings" about gestures that share a common abstract composition.

These three properties, Barnard et al. (2007) argue, are enough to account for the mental capabilities seen in great apes—including program-level imitation of food processing, tool use, advanced retention for visual sequences, mirror image recognition of "self," some theory of mind for the actions of others, and the cultural transmission of certain forms of almost dance-like actions. All of these can be achieved with purely spatial-praxic skills and would have been in place in the minds of the last common ancestor.

The two steps just described can simply be replicated with auditory-vocal capabilities. First, as with manual dexterity, differentiation of vocal utterances led to another daughter subsystem specialized for vocal articulation for the intricate and coordinated control of multiple muscles: vocal cords, lips, tongue, timing of breath, and the like (Figure 3.3; B7). Once in place within a seven-subsystem architecture, the internal bodily feedback of changes allied to vocalization can be interrelated within the multimodal subsystem with what is heard, not only in "speech by self," but with speech and related sounds generated by others. As with the emergence of a spatial-praxic subsystem, the invariants underlying vocal articulation and heard sound lead to the emergence of a "phonological" subsystem (Figure 3.3: B8). This captures abstract structural descriptions of utterances, allows mental imagery of sounds and voices "in the head," and permits the decomposition and reordering of the elements of vocal phrases and the assignment of emotion to abstract properties of what is said as well as what is seen. The eight-subsystem architecture of Figure 3.3 has a form of productive communication with some characteristics of a linguistic system.

From the architectural specification, we can reason from first principles what the owner of an eight-subsystem mind could do. Unlike a seven-subsystem architecture, it could issue really quite complex verbal "instructions" while visually demonstrating the actions required in manufacturing a spear or stone tool. In this new architecture, both vocal and skeletal actions are centrally coordinated from a single multimodal subsystem. Actions of others could be vocally rewarded or discouraged. The multimodal subsystem remains at three levels of abstraction. However, the third level now interrelates abstract structural descriptions of reorderable visual dynamics *and reorderable verbal* inputs with their emotional and cognitive significances.

At every stage along this hypothetical evolutionary trajectory, the multimodal subsystem operates by seeking to make use of invariant patterning underlying the inputs it receives. With the four-subsystem architecture, these would be confined to the here and now of sensory properties relevant for selecting among fixed action patterns. With the six-subsystem architecture, the demands of, for example, tool manufacture would require distinguishing physical properties of cores and hammer stones. Action selections guided by multimodal distinctions would have to be made in the partitioning of meat or fruit by slicing with a stone flake or partitioning kernels from nutshells by pounding a hammer onto a nut located on an anvil and so on. Byrne et al. (2004) note that distinctions within generic semantic roles proposed in case grammars (e.g., Fillmore, 1968) such as agent, object, or instrument roles, as well as other semantic properties, are *implicit in the behavior of chimpanzees*, but their presence does not mean we have to propose that they really rely on "semantic" abstractions.

The inputs to the multimodal subsystem of an eight-subsystem architecture now include the products of analyzing invariant structures in spatial-praxic dynamics and invariants underlying phonologically expressed phrases. Furthermore, the referent of arbitrary phonological forms can only be grasped by intersecting invariant patterns that have systematically co-occurred within the multimodal subsystem. The product would be *the gradual emergence and differentiation of a truly semantic coding system*. Something like the case grammar distinctions underlying the control of highly differentiated spatial, social, and vocal behavior can come to form a stable coding system in its own right and enable a final, ninth daughter subsystem to emerge that explicitly represents propositional meanings.

The emergence of the ninth subsystem (Figure 3.4: B9) brings with it a step change in cognitive capability. As with the emergence of the sixth subsystem, the transition to nine subsystems endows the architecture with the capability to *abstract deeper regularities*. These can now be four layers rather than three layers "deep." The longest chain of processing now goes through sensory subsystems (first-order abstraction), through a layer of structural description (second-order abstraction), followed by propositional analysis (third-order abstraction), and into a final multimodal synthesis of fourth-order abstract patterns underlying recurrent patterns in propositional meanings that are blended with the products of sensory processing (vision, body-states, and audition). At this point, we have renamed the mother multimodal subsystem the "implicational" subsystem to reflect the fact that it is now one of two multimodally derived systems of encoding meanings.

In this analysis, the minds of modern humans retain the signature of the four-subsystem architecture of Figure 3.2. To emphasize this continuity, the implicational subsystem of Figure 3.4 retains the connections of its all its evolutionary precursors and the original flows from the three sensory subsystems and to the effectors (marked in bold in the figure). As with all previous transitions, affect is retained in its original place—except now emotion can attach not just to abstractions of external states but to abstract ideas about the self, the world, and others. The owner of this architecture can feel success and failure in addition to the more basic emotions. Propositional meanings lack emotional charge, and the wider system can support multiple meanings. As Teasdale and Barnard (1993) point out, the depressed owners of a nine-subsystem architecture can "feel in their hearts"

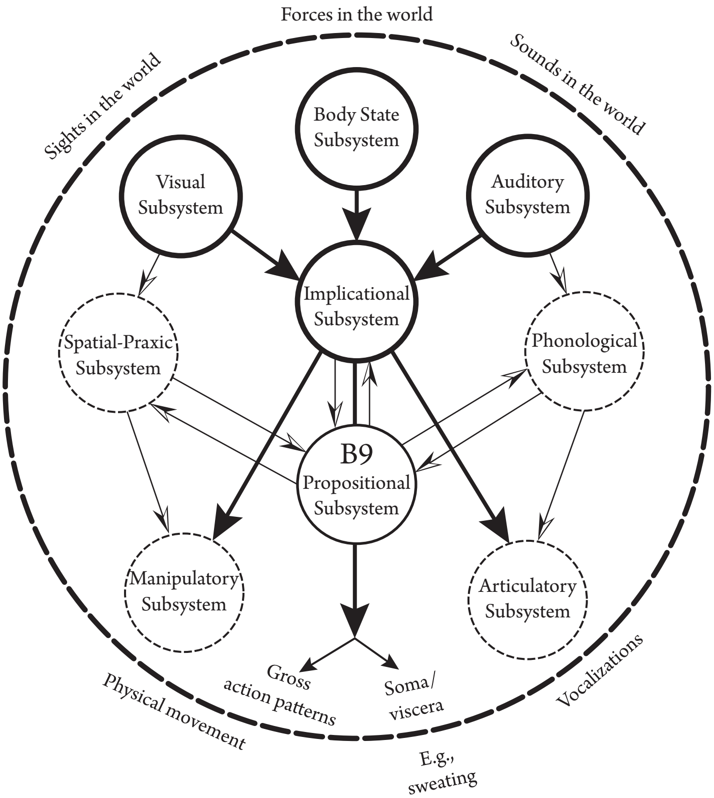

Figure 3.4 The nine-subsystem architecture of interacting cognitive subsystems proposed to account for the mental capabilities of *Homo sapiens sapiens*. (The bold arrow running from the implicational subsystem to control gross action patterns and soma/viscera is bypassing the propositional subsystem.)

all of the implicational markers of "self-as-failure" while conceptually knowing "in their head" that they have attributes of success that are indisputably "true." The implicational meaning system of the nine-subsystem architecture supplements information directly derived from the senses with conceptually derived information. It has not only "feelings" about intricate states: the content of those implicational mental states are the stuff of abstractions underlying knowledge—intuitions, wisdom, and deep expertise in, for example, science, chess, literature, and, of course, art, religion, dance, or music.

Importantly, the emergence of the ninth subsystem also brings the ability for the human mind to do more things at one and the same time. There are now three reciprocal pairs of arrows interlinking the four central subsystems. Within the dialogue between propositional and implicational meanings, the elements of "ideas" can routinely be formed, recomposed, and reorganized into either recurrent patterns known to be useful or into novel innovative forms that can be evaluated in mental simulation or by testing them in a real-world context of actual rather than imagined behavioral architectures.

All architectures along the trajectory from four to nine have specialization of mental codes, some form of concurrent processing activity, and at least second-order abstractions. At each stage, the architectural specification of the three attributes provides a scaffolding that gives a very clear basis for inferring what pattern of mental capabilities is associated with the whole architecture. No one property is more important or crucial than the other two, and all three necessarily co-evolve within a logically constrained trajectory. The changes in properties are summarized in Table 3.1.

Layered Macro-Theories and the Scaffolding of Archaeological Inferences

Our opening question focused on the issue of how the minds of archaic species of *Homo* might have differed from our own. This can now be reformulated as two specific questions coupled to a theoretical scaffolding that allows us to answer them. Can we account for the traces left by archaic species on the basis of the set of macro-theoretic properties assigned to an eight-subsystem mind? What well-dated populations can we be confident left traces consistent with the different set of properties assigned to a nine-subsystem mind?

The properties summarized in Table 3.1 provide us with clear interpretive constraints. First, only two architectures lie between that of the last common ancestor and us. Second, the first of these, a seven-subsystem architecture, differs from the six-subsystem architecture of great apes in having differentiated vocalization. This was provisionally assigned by Barnard et al. (2007) to species around during the era of *Homo erectus*. Differentiated vocalization could well

Table 3.1 **Summary of changes in three macro-theoretic properties of mental architectures across the hominin line**

Sub-systems	*Added Specialist Processing domain*	*Levels of Abstraction*	*Concurrent Processing*
5	Bimanual manipulation	3× first-order sensory domains second-order in multimodal domain 1× specialist effector domain	Concurrent image, memory, and onward processing within subsystems. Unidrectional across subsystems
6	Spatial-praxic structuring	3× first-order in three sensory domains 1× second-order structural description third-order in multimodal domain 1× specialist effector domain	Concurrent image, memory, and onward processing within subsystems. *1 internal mental dialogue* between multimodal subsystem system and spatial praxic subsystem
7	Vocal articulation	3× first-order sensory domains 1× second-order structural description third-order in multimodal domain 2× specialist effector domains	Concurrent image, memory, and onward processing within subsystems. *1 internal mental dialogue* between multimodal subsystem system and spatial-praxic subsystem
8	Phonology/ phrasal structuring	3× first-order sensory domains 2× second-order structural description third-order in multimodal domain 2× specialist effector domains	Concurrent image, memory, and onward processing within subsystems. *2 internal mental dialogues* between multimodal subsystem system, spatial praxic subsystem, and phonological subsystem

(*continued*)

Table 3.1 **Continued**

Sub-systems	***Added Specialist Processing domain***	***Levels of Abstraction***	***Concurrent Processing***
9	Conceptual/ semantic structuring Synthesis of sensory invariants now augmented by conceptual invariants	3× first-order sensory domains 2× second-order structural description 2× multimodal domains of processing propositional and implicational meanings enabling fourth-order abstraction 2× specialist effector domains	Concurrent image, memory, and onward processing within subsystems. *3 internal mental dialogues* between implicational meanings and propositional meanings and between propositional meaning subsystem and both spatial praxic subsystem and phonological subsystems

have had some role in instruction, but, in the absence of reorderable phonology, would have imposed a very clear ceiling on the communicative potential of these species in general and their instructional capability in particular. The absence of reorderable and generative phonology would also have meant that there would be little potential for differentiating abstractions within their multimodal subsystem to capture invariants of meaning underlying their vocalizations and action related to them. Apart from differentiated vocalization, abstraction and concurrency attributes are very little changed from those of great apes.

The inferred picture for any archaic species of *Homo* argued by Barnard et al. (2007) to have eight-subsystem mental architectures is different. As noted in the previous section, the theory holds that they would have had the potential to develop a highly generative verbal system of communication with reorderable phrases. They could have imagined verbal structures in their minds and develop abstract invariants underlying actions and speech as third-order multimodal invariants. The architecture nonetheless again has a clear ceiling—the architectural arrangement means that the meaning system would be constrained to rather "concrete" invariants. Its multimodal subsystem would be totally absorbed with managing its spatial-praxic, verbal, and bodily responses. There is no capability to reflect on meanings or, for example, to think about how to make a better tool while concurrently making one. It lacks the capability to reframe meanings concurrently.

A nine-subsystem architecture has two types of meaning that enable it to transcend these limitations. To reiterate key points made earlier, it has wisdom/intuitions and also the capability to represent facts, properties, and interrelationships. Emotion in this mind attaches only to implicational meanings and not to propositional meanings. It can be a rational and an emotional mind. In addition, within the dynamic exchanges between the meanings, the processing of implicational meanings can generate new propositional meanings on the fly (referents, their properties and relationships). Reciprocally, propositional meanings can now enrich implicational meanings in a way that enables the architecture to *synthesize and generalize over many interrelated "facts."* It can see relationships that would remain only implicit in the single multimodal subsystem of an eight-subsystem architecture. The products of propositional processes can also directly interpret (input flow) and control (output flow) phonological forms while also directly interpreting (input flow) and controlling (output flow) spatial praxis. The direct inference that an owner of a nine-subsystem architecture can walk, talk, and think concurrently derives from the reordering or substitution of meanings in real time.

From the attributes in Table 3.1, we can draw inferences about the mental capabilities of hominins to innovate or to communicate. However, when embedded in our layered framework of macro-theories (Figure 3.1), the requirements on specifically archaeological inference become more intricate. For example, it follows from our analysis that third-order "meanings" can be differentiated within an eight-subsystem architecture. We surmise, for example, that an eight-subsystem architecture initially emerged in Africa sometime prior to 500 kya. Although limited at the outset, differentiation would progress along with expansion in behavioral repertoire as the potential of eight-subsystem architectures was exploited. Any increases in the repertoire supported in behavioral architecture would require differentiation of cognitive capabilities to identify and distinguish the different states for the initiation of those actions as well as for the execution of the different actions or verbalizations about them. This approach recognizes that there could be either convergence or variation in behavioral repertoires among groups that shared this architecture.

The impact of the differentiation of tools provides a pertinent illustration (Barnard et al., 2007; Byrne et al., 2004; Davidson & McGrew, 2005). Without cutting tools, the only way of dividing foodstuff is to tear it with limbs or teeth. Because tools were made in different forms, actions and vocalizations concerning those actions would differentiate perhaps to distinguish cutting a small piece off a carcass, slicing it into parts, chunking, or pounding it. There would likely be associated actions and phrases related to the treatment of food, possibly including passing it to another agent, laying it down, or hanging it up to dry. For an eight-subsystem architecture, these could well bear similarity relationships within third-order abstractions, but they would remain referentially distinct.

Differentiation is clearly a prerequisite to establish a fourth-order invariant of "division or subdivision." However, the invariants underlying division would remain implicit in a one-level multimodal synthesis. Hominins with an eight-subsystem architecture would have been breaking, cutting, separating, and dividing in other ways without the capacity to recognize that all of this behavior involves more abstract invariants ("division into parts") capturing what they had in common. We also suspect that creating multipart tools is conceptually easier once the concept of division (and hence the construction of combinations) is possible.

A nine-subsystem architecture could not only explicitly represent the abstract concepts of division and subdivision of meat parcels, it could also figure out that this idea could work across animate agents, inanimate objects, fluids, thoughts, or numbers. The fact that these deeper relationships become thinkable means that knowledge originating in one domain can be generalized and put to good use in another. So the same abstract concept could also apply to the division of a group into smaller groups for foraging and hunting. This happens among many primates, but only with nine subsystems could the idea persist that the absent members were part of the same group. Although a nine-subsystem architecture has the potential to establish an abstract concept like division, the concept would again arise out of the repertoire in behavioral architecture. As a result, differentiation of abstraction would only accrue over time and then only as a consequence of the activities and verbal dialogues that make up the behavioral architectures in place at the time.

This has significant implications for interpretations in archaeology. In our argument, a fully exploited eight-subsystem architecture would have a system of implicit meanings. The potential expression of those meanings in behavioral architectures could well be not significantly different from a rather pristine and very underexploited nine-subsystem architecture. This could occur where there had been little time or opportunity for a culture to differentiate a powerful range of new abstractions and exploit them. Even though the nine-subsystem architecture has the capability, the requirements for that capability to be evidenced may not be in place. Additionally, an extensively exploited eight-subsystem architecture may well require more neural circuitry and hence a larger brain to achieve less than a more computationally efficient nine-subsystem architecture.

With respect to layered macro-theories (Figure 3.1), this implies that aspects of neural architecture, the resulting behavioral architectures, and their physical traces in bones and stones may be highly ambiguous around the period of transition between an eight- and a nine-subsystem species. There will be some sort of *event horizon* around which we can never really be confident about the precise structure of the minds involved. To take a topical example, the attachment of emotion to an object could be founded on implicit semantic distinctions rather than explicit ones—thrusting spears, digging sticks, the odd unusual pebble, beads, or even the occasional raptor or corvid feather (Finlayson et al., 2012; Peresani, Fiore, Gala, Romandini, & Tagliacozzo, 2011). Similar issues concerning inferences about symbolism and body ornamentation in Neandertals are discussed by Garofoli (2014). In these cases, we need enough evidence to be confident that the physical traces were not produced by a species with an eight-subsystem architecture.

We could be more confident if we find a set of changes occurring in particular places or populations for which there is an interlinked overall package of evidence. The package would require fourth-order abstraction indexed by generalization of key properties across domains of action, coupled with evidence of value or emotion attached to those abstractions. These would be accompanied by evidence for rapid innovation of the sort that suggested the agents were able to think concurrently with doing and talking. Furthermore, we would potentially also want to assess whether the evidence could derive from even simpler architectures whose theoretical properties are equally well specified. From comparative and evolutionary psychology, as well as archaeology, there are three domains where there is a body of evidence that can be traced all the way from great apes, through our two hypothetical seven- and eight-subsystem mental architectures, to a nine-subsystem mental architecture.

These domains concern nutrition, tool manufacture, and medicine. At a lower bound of third-order abstraction (a six-subsystem architecture), we know a good deal about great apes' processing of food stuffs (Byrne & Byrne, 1993) and their use of tools and material culture (McGrew, 2004), and we also know that today's great apes are able to exploit medicinal properties of plants (Huffman & Wrangham, 1994). Equally, at an upper bound, we know much from modern anthropology about nutrition, tool use, and medicine in hunter-gatherer societies: how people hunt with multipart weapons, trap and forage for plants; how they remove toxins from plant material and cook; and how they use ochre as an astringent for sealing wounds, as an insect repellent, or as sunblock (e.g., see Velo, 1984). In all of these domains, signatures in behavioral architecture index abstraction, innovation, and how value (or emotion) attaches to abstractions about behavior in the physical and social world. This includes more mystical or "spiritual" inferences about expressions of agency.

Those who favor a late emergence of modern minds typically seek evidence for, and rest their case on, complex patterns in material culture such as traps (Coolidge & Wynn, 2009, 223–227), representational art (Davidson, 2013), or indications of ritual (Ross & Davidson, 2006). Yet, evidence from southern Africa around 90 kya is strongly suggestive of important earlier developments (Henshilwood, d'Errico, & Watts, 2009; Henshilwood et al., 2011). Systematic marking of ostrich egg shells (Texier et al., 2010), the clear evidence for the use of heat treatment in compound adhesive manufacture (Wadley, Williamson, & Lombard, 2004), and the systematic heat treatment of stone itself (Brown et al., 2009), if not yet definitive (see, e.g., Zipkin, Wagner, McGrath, Brooks, & Lucas, 2014), probably imply populations with a package involving fourth-order abstraction, generalization, and the attachment of some significance or value to abstract marks.

Food processing furnished the strongest evidence that great apes could substitute and reorder elements of spatial praxis (Byrne & Byrne, 1993; Byrne & Russon, 1998) and led to the idea of program-level imitation, consistent with the capabilities of a six-subsystem architecture with deeper abstractions than its precursors. The case of compound adhesive manufacture is particularly instructive because it furnishes comparable evidence for the reformation and substitution not of actions, but of abstract concepts. The physical traces so far analyzed show that compound adhesive was used in the manufacture of backed stone tools and that the recipe included gum, an ochre filler, and a heat treatment process (Wadley et al., 2009). Reconstructive experiments have also demonstrated that the heat treatment process itself has to be kept inside limits or the resultant adhesive would be prone to fail (Wadley, 2005). The fact that different ingredients are used in these recipes can be argued to be indicative of the substitution of elements with similar abstract properties. Heat treatment is indicative that the adhesive makers could well have been able to capitalize on abstract constructs such as the "consistency" of a mixture in early phases of making and then perceptual properties of the resulting amalgam to titrate the intensity and duration of heat application. Because all of these would vary slightly over the recipes, this domain has all the hallmarks of the modern expertise of a blacksmith (such as the work of the Kellers discussed by Wynn, 1993). Expert knowledge is intricate and often composed of a combination of overt communicable "facts" (propositions) and implicit, less articulable knowledge (implicational synthesis of conceptual facts and multiple sources of sensory information) about when something is ready or not yet ready: for example, when iron shows some combinations of appearance, sounds, and physical resistance to hammer. It would also be consistent with the ability to innovate in a new environment where alternative ingredients with the right properties have to be used and the process of manufacture adapted to suit them.

Importantly for the idea of intersecting evidence within behavioral architecture for inferences about mental architecture, we can also consider whether there are now the beginnings of a case for generalization over domains. Ochre is also mixed with spit, rather than gum, for application to wounds or with animal fat or oil when applied as a sunblock or as an insect repellent (e.g., Jones, 2007, 348–349). It is also mixed to produce paint (Henshilwood et al., 2011), and we can expect that only certain combinations in each case have the intended effects. Similarly, mineral salts and spices with little nutritional value of their own but with implications for flavor, health, and well-being are routinely included in food recipes. If some deeper abstractions about materials with similar properties used in the combination of ingredients in cooking, perhaps requiring selective use of heat, could also be established in the future either from physical traces in the record or in reconstructive work, then that might constitute intersecting evidence for a nine-subsystem architecture.

What is in evidence early in the exploitation of a mental architecture may adapt as behavioral architectures evolve over time. Early in the exploitation of a nine-subsystem architecture, the use of ochre may primarily reflect health and well-being when applied to a body and indicate some attribute linked to identity of content or ownership when applied as a pigment to shells. Only after perhaps many tens of thousands of years of developments in behavioral architecture and culture may its use become an abstract body ornamentation with emotional significance or representational art associated with ritual or votive practices. Likewise in the case of tools, it may have taken much development and maturation in behavioral architecture before populations with nine-subsystem architectures discovered traps.

Conclusion

In sum, the present approach to mental architecture, and the trajectory it suggests was followed across the hominin line, has been specific about the relationships among mental capabilities and the properties of whole minds that impart capabilities into the behavioral systems that leave archaeological traces. The approach recognizes and gives form to the interdependences among layers of explanation that gives rise to potential ambiguities in the archaeological record and suggests how we might best resolve them. Where the intersecting results can be shown to depend on abstraction, innovation, and being able to think and communicate concurrently about what is going on, then our macro-theoretic framework would hold that a nine-subsystem architecture was in place. If only an eight-subsystem architecture was in place, there should be no wider evidence for abstraction and semantic generalization and rapid innovation. To date, it would be very hard to make the case for more than eight subsystems in any archaic species of *Homo*. It should now be possible to scaffold the inference of differences between minds in hominin populations on macro-theories that interlink neural, mental, and behavioral domains, rather than relying on inferences grounded only on heuristic empirical associations.

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4

Material Engagement and the Embodied Mind

LAMBROS MALAFOURIS

Introduction

What is that thing we call "mind" in the archaeology of mind? What is "cognitive" about cognitive archaeology? The reason questions of that sort are usually neglected is because we take them for granted. We take them for granted not because we have the answers or because we think they are trivial. Rather, we take them for granted because we feel that answering those questions is not really our job. We trust that it is the responsibility of other, maybe better equipped, disciplines like philosophy, psychology, or neuroscience to define and demarcate the cognitive. The job of archaeology is to adopt this preformed experimental or theoretical construct and apply it to the material record of the past. Our job is not to question the construct or to test it against our findings; rather, it is to see what we can learn about its evolution or how it can help us explain some aspects of the archaeological record. Of course, all that makes very good sense. It is inevitable and necessary that cognitive archaeology must draw on and work closely with cognitive sciences. Cognitive archaeology is cognitive science or it is nothing. But there are also some hidden caveats. Every time we borrow concepts, models, and assumptions from other disciplines we should not forget that, for the majority of them, figuring out how the mind works has always been more important than figuring out how it got to be here. Moreover, words like "material culture" don't even exist in their vocabulary. In contrast, cognitive archaeology has an epistemic obligation to the study of materiality and of long-term change. Importantly, it might well be that understanding how the mind got to be here could help us understand how it actually works. Failure to prioritize and respect those distinctive epistemic features of cognitive archaeology needlessly restricts our ability of theorizing, it undermines the empirical status and the explanatory power of the archaeological record, and it may also deny the very possibility of making a genuine contribution to the study of mind. Thus, before we can ask when did the human mind-as-we-know-it arise, we need first to acquire a deeper archaeological understanding of what exactly the mind-as-we-know-it is and does. That is, we need a contemporary archaeology of mind.

Returning to the ontological questions I raised at the beginning of this chapter, I am worried by the way it becomes increasingly fashionable nowadays to think of the mind as a representational or neural entity that exists inside people's heads. I suspect many archaeologists would also like to object to that premise and argue that the mind must be more than a brain. Yet evolutionary cognitive archaeology (ECA) is currently lacking a joint systematic effort focusing on what exactly "more than a brain" means and how it affects archaeological practice and interpretation. As a consequence, and contrary to what many researchers might think, *cognitivism* remains by far the dominant paradigm in the archaeology of mind—at least implicitly. This can be also testified by the pervasive influence that evolutionary psychology and the various neo-Darwinian trends have on archaeological thinking (both of which are inherently defined by the logic of representationalism and computationalism).[1]

No doubt important progress has been made in recent decades introducing new sophisticated theoretical models and concepts that allowed ECA to move beyond the initial emphasis on general issues of symbolism and language. Representative examples can be seen, for instance, in (a) the work of the editors of this volume on the evolution of human *executive functions* and their hypothesis that the enhancement of working memory capacity offers a good example of that shift toward a more systematic ECA (Coolidge & Wynn, 2001, 2005, 2009); (b) the recent innovative attempt by Miriam Haidle showing how the underlying perceptions and behavior in the process of manufacture and use can be coded in cognigrams and effective chains (Haidle, 2010, 2014; Lombard & Haidle, 2012); (c) the series of neuroimaging experiments by D. Stout that opened a new window on brain function and organization (Stout, Toth, Schick, & Chaminade, 2008; Stout & Chaminade, 2007); (d) the new methodological advances in the field of palaeoneurology (Bruner, 2003, 2004, Bruner & Lozano, 2014) that enable a more nuanced interpretation of the observed variation in endocranial morphology and a better understanding of the patterns of growth (changes in size) and development (changes in shape) of the brain as reflected in the available record of fossil endocasts; (e) the ecologically inspired dynamical approaches to neuroarchaeology (e.g., Barrett, 2013; Bril, Roux, & Dietrich, 2005; Davidson & Noble, 1989; Malafouris, 2004, 2008*a*, 2010; Malafouris & Renfrew, 2008; Nonaka, Bril, & Rein, 2010); and, finally, (f) the British Academy's Centenary Project, "From Lucy to Language: The Archaeology of the Social Brain," which brought together psychology and archaeology to explore the hypothesis that it was our increasingly complicated social lives that drove the encephalization of the hominin brain (Gamble, Gowlett, & Dunbar, 2011; Gowlett et al., 2012).

These are but a few representative ongoing research projects that speak of the vitality and expanding nature of ECA. However, in spite of all this progress and multiplicity of perspectives, I sense that ECA struggles in coming to terms with the nature of mental action and the way in which the structure of the environment where action occurs and the range of material and semiotic resources available figure into its organization. A simple review of the literature from the past three decades or so will reveal a persistent epistemological anxiety over the boundaries of mind and the existence of a huge ontological gap separating cognition, action, and materiality. I believe the main source of this anxiety is well known and comes from the following assumption that all cognitive archaeologists share: *we cannot dig up minds*. Archaeology can only have empirical access to the material products or the behavioral remains of past minds (which also explains the need to provide bridging arguments between the archaeological record and psychological models).

Where is that mind that we cannot excavate? Everyone will recognize, for instance, that tool-making and -using is something we do; namely, a physical act. However, when it comes to understanding its mental components, we immediately assume that this is something that happens within us, specifically in our heads. As a result, we perceive the mental and the physical component of every act of making as two different things that happen at slightly different times in different locations, with the former always causing the latter. This assumption is so deeply entrenched it blinds us to any alternative conceptualization. The accumulating literature on early bodily ornamentation by means of body painting and shell beads provides another classical example of this tendency, one where the focus on the putative symbolic dimension of those artifacts and practices very often disregards the bodily activities producing and the bodily and social skills enabling them. Instead, mentalist models and symbol-based interpretations have become the norm, as if meaning in the specific case could have been expressed or constituted by other than bodily and material means (but see; Garofoli, 2014; Iliopoulos, 2015; Malafouris, 2008*a*).

I am afraid that by neglecting ontology we have weakened the epistemological basis of cognitive archaeology and the unique explanatory power of the archaeological record. This neglect has been intensely damaging to archaeological understanding of human cognitive becoming, maybe more damaging than the difficulties and restrictions posed by the paucity of the archaeological and fossil record.

In searching this volume for new "formal cognitive models," we risk repeating that old mistake. Thus, my aim in this chapter is to try flesh out a possible alternative that argues against this separatist logic that clearly prioritizes the brain as the seat of mental life. The material engagement approach (Malafouris, 2013) that I advocate insists, on the one hand, that the brain can only be understood as one element of a larger intelligent bodily system that incorporates material culture and, on the other hand, that, contrary to what many archaeologists think, the physical location and ontology of human intelligence remains an open question (see Figure 4.1).

So far as the discussion of "formal cognitive models" is concerned, this chapter will focus specifically on embodied cognitive science, which has become one of the foremost areas of study and research, with a variety of applications from the study of perception and language to the study of social cognition, emotion, consciousness, memory, and learning and development (see Shapiro, 2014). Not surprisingly, the label *embodied cognition* (EC) is typically used to refer to a variety of theories, some of which are more radical than others. As a result, despite the growing contemporary interest in EC, many unresolved problems remain, and there is little agreement about just what it means to say that *the body shapes the mind* (Gallagher, 2005; Kiverstein, 2012). There are several important questions and potential caveats that I will try to address.

One question concerns what is meant by "body" here. I will argue that if notions of embodiment are to have any real explanatory value, they ought to mean something different from the brain. This is not because the brain is not an inseparable part of the body; rather, it is because if, in our discussion of embodiment, we allow the brain to qualify as part of the body we run the risk of trivializing the claim that the body is crucial to mental life and we end up with some

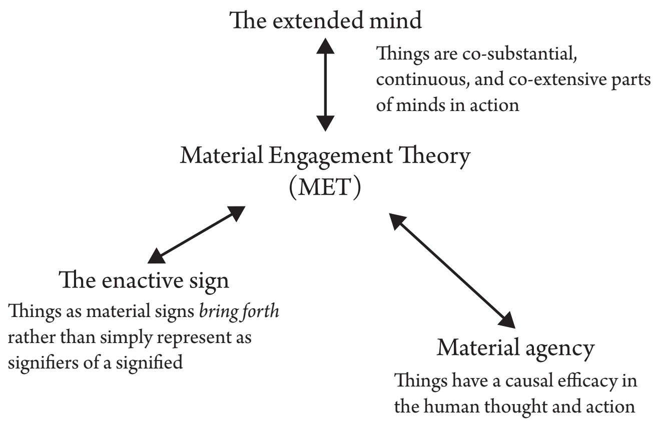

Figure 4.1 Material engagement theory (MET) as an explanatory path develops along the lines of three interrelated working hypotheses that can summarized as follows: (a) the hypothesis of extended mind, which explores the constitutive intertwining of cognition with material culture; (b) the hypothesis of enactive signification, which explores the nature of the material sign not as a representational mechanism but as a semiotic conflation and co-habitation through matter that enacts and brings forth the world; and, finally, (c) the hypothesis of material agency, which explores agency not as a human property but as the emergent product of situated activity.

version of brain identity theory (Goldman & de Vignemont, 2009, p. 154). What I call "embodied cognitivism," namely, the limited view of embodied mind as somehow contained, localized in, caused by, or identifiable with the brain must be overcome. The embodied mind must be more than a brain or it is an empty concept. This last point is worth stressing.

Another basic question in this context concerns the nature of the contribution of the body to cognition and about whether this contribution can be accounted for by way of classical computational models or whether something more radical is needed. More important for my purpose in this chapter is the question of material culture fits into this emerging picture of EC. The most common view of extended, embodied, and distributed cognition is the one largely compatible with computational functionalism, where external representational elements are taken to be constitutive components of the cognitive architecture, given their ability to implement and facilitate (by means of external storage and distribution) information processing. It is necessary when we speak of embodiment as the condition of cognitive extension by means of external representations to clarify some important, often implicit, distinctions, such as those between derived and nonderived content and between causal influence and constituency (Wheeler, 2014, p. 378).

Viewed from the perspective of material engagement theory (MET), some meanings and uses of the term "embodied and extended mind" are certainly more helpful than others. One of my aims in this chapter is also to clarify the meaning that the notion of EC has in the context of MET (Malafouris, 2013). I will differentiate "weak" embodiment from "hard" or "radical" embodiment and argue that the material engagement approach subscribes to the latter version, according to which cognition is grounded in situated action and constrained by the specific kind of body we possess. It is important to clarify here that the meaning of the term "body," far from reductive and fixed, refers to the details of bodily implementation (neural and extraneural) and action-taking potentials because those can be determined by the nature of local interactions, cultural practices, and prostheses. The latter goes against the functionalist claim (often implicit in some versions of extended mind theories) that the same kind of cognitive process or state can be realized in different kinds of bodies or material instantiations. In contrast to the functionalist principle of multiple realisability (for some, the key premise of artificial intelligence or AI), for MET, different kinds of bodies/embodiment equal different kinds of minds. MET insists that only a thorough reconfiguration of the relation between cognition and material culture can provide cognitive archaeology, and by extension cognitive science, with a feasible alternative framework to battle the cognitivism of classical evolutionary psychology. The organism's worldly engagements become the new analytical unit for the study of mind. Material engagement constitutes a level of analysis not reducible to the individual. The chapter ends with some comments on what embodiment brings, specifically, to the archaeology of mind and the study of material culture.

How to Understand the Embodied Mind

What does it mean to describe cognition as embodied? The general idea of the embodied mind is quite simple: our ways of thinking are deeply rooted in our modes of bodily movement and sensation. The body is not, as is conventionally held, a passive means of implementing the necessary perceptual input for representing the outside world inside the head nor is it an output device for commands generated by the processing of those internal representations; by contrast, it is an integral component of the act of thinking. What does this mean exactly?

As mentioned, there is diversity of opinion and ongoing debate about the exact status of the body and the senses in relation to human cognition (Chemero, 2009; Gallagher, 2005; Rowlands, 1999, 2010, 2014; Streeck, 2009; Wheeler, 2005; Wilson, 2002). Embodiment seems to mean widely different things to different EC theorists. To help us navigate this unfamiliar conceptual terrain, I will draw on a useful distinction, proposed by Andy Clark (1999), between two varieties of embodiment: “simple” versus “radical” embodiment. Clark introduces those terms to “distinguish two different ways to appeal to facts about embodiment and environmental embedding” (p. 348). In particular, the weaker version, dubbed “simple embodiment,” offers a moderate alternative to cognitivism by treating “such facts as, primarily, constraints upon a theory of inner organization and processing” (p. 348).

A good example to illustrate that is the relationships among mind, hand, and gesture. Consider the classical question of “why do we gesture when we speak?” Traditionally, the most common answer is to see gesture as a byproduct of verbal expression. On this view, by gesturing while speaking we facilitate verbal processing, expression, and communication. For instance, studies have shown that more gestures with semantic content are produced in face-to-face interaction than when there is no visual contact. It has also been proposed by Krauss et al. (Krauss, Chen, & Gottesmann, 2000) that gesturing during speech results in “cross-modal priming,” which promotes lexical access and retrieval (especially when speech content is spatial in nature) or that gesture rates are higher when lexical access is difficult. Seen in this way, gestures are merely communicative tools that reflect internal cognitive processes. Meanwhile, a parallel line of experimental research has shown that gestures might have a more direct causal impact on the way we think. The work of Goldin-Meadow, to give one representative example, provided ample evidence that gesturing reduces cognitive load and thus frees speakers' cognitive resources to perform other tasks (e.g., memory tasks; Goldin-Meadow, 2005; Goldin-Meadow & Wagner 2005, 238). Moreover, the so-called embodied simulation theories have been trying to ground language in bodily states and action by arguing that concepts directly evoke action information (Gallese & Lakoff, 2005). For instance, listening to sentences that describe actions engages the visuomotor circuits that subserve action execution and observation (Tettamanti et al., 2005). Simulation theories see the offline recruitment of the same neural networks involved in perception and action (e.g., Jeannerod, 2007) as a form of embodiment. That is why gestures had been described in this context as "visible embodiments" of internal simulations (Hostetter & Alibali, 2008). In short, language and thought processes are dependent on the brain recruiting sensorimotor representations/activations.[2]

The preceding studies offer a representative sample of "simple embodiment." Notice that there are two underlying assumptions here: first, that since gestures and speech are part of the same cognitive source, the former can provide a window on the hidden inner mental operations of the later. Second, that gestures and bodily movements only execute already preformed sensorimotor neural instructions and thus they appear to be *cognitively trivial* (Pouw, De Nooijer, Van Gog, Zwaan, & Paas, 2014; Radford, 2009).[3]

Those weak perspectives on EC can be useful when it comes to understanding the links between high-level cognitive processes and low-level bodily experiences in the brain, but they also serve to reiterate and hide the traditional drawbacks of cognitivism. Specifically, they create the illusion that EC and classical representational cognitive science are compatible and subject to limited adjustments (e.g., the recognition of the importance of organism's sensory–motor experience, which nonetheless become realized by means of neuronal representations). I am not saying that the embedding of cognitive processes in brain circuitry is wrong, as long as one specifies what this embedding means and how it relates to the body and the material world. The hand and the brain interact, and to reduce the action of the former to the latter is to miss the very point of introducing the term of "embodied cognition."

Examples of simple embodiment abound in cognitive archaeology, with the majority of researchers still relying heavily on representational and computational neo-evolutionary psychological assumptions that effectively isolate and prioritize hominin brain evolution over the body and the material record. Attention to the roles of embodied action and material culture, in such cases, is merely a means of testing ready-made psychological and, more recently, neuroscientific constructs and models against the archaeological record.

Take, for instance, the example of tool use and manufacture. Obviously, it makes little sense to account for the evolutionary and ontogenetic significance of tool use on the basis of a disembodied view of mind. And yet this is precisely what is happening in the majority of studies where the focus on embodied and situated aspects of action is not aiming to understand how the body moves and thinks in order to elevate its importance in explaining the nature and origins of human cognitive activities and higher cognitive functions. The underlying assumption remains that mental operations are located inside the head in the classical computational fashion, largely detached from the workings of the body that no doubt they move and control. As a result, concern with bodily action and skill simply provides an additional empirical constraint for understanding the origins and transformation of those predefined inner representational and neural structures. In other words, bodily experience and gesture are important not in themselves but only when they contribute to an account about the inner representational realm.

Is there another way to understand the cognitive life of gestures as embodied physical acts? Can it be argued that bodily gestures are able to realize or provide material vehicles for cognitive processes (Wheeler, 2013, p. 269)? I argue that tools and the embodied acts that their use and manufacture affords and invites are not simply the products of mental action but also central to the organization and constitution of action. This brings us to the second, stronger version of embodiment dubbed "radical embodiment."

Radical Embodiment and Material Culture

Radical embodiment goes much further and treats the body, its material sociotechnical extensions, and specific developmental and environmental dynamics as profoundly altering the mind and, by extension, the "subject matter and theoretical framework of cognitive science" (Clark, 1999, p. 348). This attitude of analytic decentering has large implications for how we study the mind in the past or in the present. Adopting the stance of radical embodiment requires more than the rediscovery of a more sophisticated "motor homunculus" map (Penfield & Rasmussen, 1950)—the old idea of the brain as the central executive controller must be rejected. The interdependence of hand and mind that the EC paradigm speaks about implies a different conception of human becoming. This new conception of human becoming requires us to abandon the view of the hand as an instrument of the brain and embrace the possibility that it might well be that it is our hands and our bodies that move our brains, shaping the way we think. In the words of the philosopher Andy Clark (1997):

> It requires us to abandon the idea (common since Descartes) of the mental as a realm distinct from the realm of the body; to abandon the idea of neat dividing lines between perception, cognition, and action; to abandon the idea of an executive center where the brain carries out

> high-level reasoning; and most of all, to abandon research methods that artificially divorce thought from embodied action-taking. (p. xiii)

No doubt grounding cognition in bodily experience is the necessary step for bypassing the conventional dualisms and asymmetries and for recognizing that the body does more than house a brain, provide the inputs (perception), and externalize the outputs (action) of its operation. But if embodiment is to give real-world action a primary role in the study of mind, then any distinction between the "inner" and the "outer" worlds must be rendered meaningless.

Indeed, if we accept that the human body in its basic capacity for movement and action provides the experiential foundation of an embodied human mind, we have to admit also that none of the kinesthetic image schemata and sensorimotor skills that constitute this minimal preconceptual structure of our bodily selves can be experienced outside some context of material engagement. In such contexts of situated action, however, the boundaries of the embodied mind are determined not solely by the physiology of the body, but also by the constraints and affordances of the material reality with which it is constitutively intertwined. In other words, if, as some embodied mind theorists suggest, the body is not a mere channel for inputs and outputs but instead must be seen as a genuine part of cognitive processes, then the same logic must be extended to incorporate the relevant material environment.

Seen in this radical sense, embodied cognitive science presents a number of challenges for the archaeology of mind. For one thing, embodiment as a condition of material engagement is inherently situated. Specific embodied skills, like stone tool–making, seen as forms of manual activity and situated learning (Lave & Wenger, 1991), are best explained without appeal to abstract rules or representational schemata. Conventional accounts of tool making that wrongly associate cognitive activity either with internal planning or with some neural activation pattern continue to disregard the act of making as a direct manifestation of embodied intelligent action. Those representationalist accounts of cognition cannot explain the varieties and complexity of skillful material engagement characteristic of the cognitive life of our species because they neglect what matters the most (i.e., the priority of material engagement).

The hand-held tool or the pointing finger are not mere outputs of the cognitive system but have a constitutive role for at least some of the thought processes in the act of making or speech production. In other words, bodily acts and prosthetic gestures generate and constitute rather than merely execute thought processes (Malafouris, 2012; see also Clark, 2013).

The implicit image we need to avoid here is that of a central self-conscious cognitive agent or executive central controller who orders, guides, and controls the movement of the hands and who, in some sense, is using the body to execute and externalize a preconceived mental plan from the head to the world through the stone. We need to replace this internalist and inherently dualistic vision of *projective* mentality with an enactive, distributed, and inherently dynamic vision of *participatory* mentality. This is what the material engagement approach does. Thus, unlike the great majority of approaches to the study of human cognitive evolution that remain committed to representationalist thinking, MET subscribes to a process ontology of material culture and thus to an anti-representationalist enactive conception of EC (Gosden & Malafouris, 2015; Hutto & Myin, 2013).

In the previous sections, we have seen what embodiment brings to the study of cognition. We have also discussed the radical view of embodiment that the material engagement approach adopts. In the last part of the chapter, I want to examine the implications and scope of EC for ECA.

Embodied Cognitive Science and Archaeology: Implications for ECA

This emphasis of embodiment and being in the world as the fundamental modes of existence also implies that the traditional vocabulary of psychological traits and processes itself becomes questionable. This does not mean that we should only study bodily "sensorimotor" interactions over or against higher cognitive functions or that one can no longer speak, for instance, of executive functions or imagination. Nonetheless, it does mean that those "higher" cognitive functions need some rethinking and reconceptualization in order to accommodate the implications that the embodied mind perspective brings with it. Consider, for instance, the idea of working memory as the ability to gather and process information. From the perspective of embodied cognitive science, the conventional psychological definition of this notion by Baddeley (2003) as the ability to hold information in attention and process it (e.g., the capacity to hold a list of numbers in mind without changing their order) is unhelpful. The meaning of the term "information" is now different. You cannot just simply retain the classical internalist conceptualization of working memory capacity as part of human executive reasoning ability that takes place solely inside the head and simply add a body. Your understanding of what working memory is and how it emerges must change. For instance, even at the level of simple embodiment, one would expect that the manner in which information is encoded into working memory would influence how that information is processed and made meaningful. From a radical embodied cognitive science perspective, however, the situation is far more complicated. Not only the "content" of memory is encoded in multiple ways and is distributed in different (neural and extraneural) representational formats and material scaffolds, but, very often, discussion of content and representation is misleading. Terms like "information," "encoding," "holding," or "processing" take on a new meaning.

As we discussed, the EC approach suggests that our bodily processes and physical engagement lay the foundations for all mental processes. The executive functions are no exception. Interestingly enough, research in developmental psychology assessing the interaction between bodily engagement (e.g., of hand gestures) and performance on executively demanding tasks demonstrates a positive relationship between them. In particular, developmental studies looking at children's performance on executive functioning tasks requiring varying degrees of bodily engagement point out that working memory and other executive skills in children (e.g., their ability to switch between different strategies) can be enhanced via interaction with physically engaging technologies (e.g., computerized tasks; see Best, 2010, 2012; Blair & Razza, 2008).

What these findings indicate, relevant to the so-called "enhanced working memory" (EWM) hypothesis advanced by Tom Wynn and Fred Coolidge, is that, after all, there is no need to infer a sudden genetic mutation in our ancestors brains causing an enhancement of working memory capacity. Once you abandon the "prescriptive logic" of selectionism (Varela, Thompson, & Rosch, 1991, ch. 9) it is no longer necessary that change should come from "within." Rather, moving beyond the adaptationist framework, a change in the ecology of material engagement will do. Even if one could prove that such a mutation took place, it would still have very little explanatory power. The organism and the environment, brain, and culture are mutually specified and codetermined. This is why the developmental dynamics and the specific details of material engagement matter when archaeology comes to deciding about what, exactly, had evolved and how, where, and when it happened (Malafouris, 2013). Although for developmental psychology the recognition that bodily movements aid or modulate cognitive processing might suffice, we should keep in mind that from an evolutionary perspective bodily movements *are* minimal cognitive processes.

The fact that sometimes bodily movements, actions, and forms of material engagement can be argued to merely support, mediate, or just correlate with neural processes and thus should not be considered as part of them does not mean that, in many other cases, those extraneural events of bodily action and material engagement are not strictly speaking parts of our active minds.

The importance of *metaplasticity*—namely, the fact that we have a plastic mind inseparably constituted with a plastic body and culture—is precisely that it allows us to become what our given cognitive ecology affords (Malafouris, 2010, 2013, 2015). The internalist/externalist distinction is not one of ontology but of everyday practice and ways of thinking and being in the world.

In fact, returning to the EWM hypothesis, one may well propose that, far from signifying a *fixed stage* in human cognitive evolution differentiating between "modern" and "pre-modern," it should better be conceived as an ongoing dynamical "non-modern" *state* of human becoming where, paradoxically, reducing the working memory load by engaging material signs and techniques becomes the most efficient strategy for enhancing human memory and extending the amount of thoughts to be consciously entertained, as well as the manner by which they become attended in a variety of media.

This is also why I believe that notions like the "modern mind" or "behavioral modernity" are so unhelpful, if not entirely misleading. Maybe a few decades ago they offered cognitive archaeology a focal point for organizing the complexities and irregularities of the early archaeological record. These notions are now obsolete and should be abandoned. Cognitive archaeology has matured and needs a more sophisticated and precise theoretical vocabulary. To this end, current debates and theorizing in fields like semiotics, philosophy of mind, and material culture studies might be especially useful.

In any case, what it is important to clarify here is that neither MET nor radical embodied cognitive science are compatible with the notion of "cognitive modernity" or the foundational premises of current neo-Darwinian thinking in archaeology and beyond. Having said that, I also want to argue that MET is largely complementary to, and in some instances builds on, contemporary accounts in ECA that, although they make use and refer to those notions, do so for the sake of established convention (and maybe also for the sake of implicit how-to-get-published norms) rather than any explicit commitment to what those notions really stand for or imply about the shape of human evolution and the nature of human cognition. It is important to realize, if cognitive archaeology in general and ECA in particular is to become an active contributor into the sciences of mind, that different disciplines aim at answering different kind of questions using different methods and data. As archaeologists, we have responsibility to make the best use of what we have, respecting the properties of material culture and constructing our own theories and epistemic practices.

I argued previously that a common conservative tendency in the study of embodiment is that of retaining the idea of computation at its heart but opening up space for the possibility that the body (and by extension the environment) can also potentially implement information processing. I have shown that this conservative tendency or strategy, although appealing from a "unified" embodied cognitive science perspective, has a number of problems. For those who still would like to retain a computational outlook, preferring or finding more productive the epistemic tidiness of simple embodiment over the ontological messiness of the radical embodiment advanced in MET, I have a simple piece of advice: cognitive processes realized by acting human bodies, working in concert and engaging the material world, unlike algorithmic disembodied processes realized by computing machines, have a natural tendency to flow through whatever material in which it is cheaper to implement them (cf. Kirsh, 2010, p. 442). Now it is well known that neural tissue has always been a particularly expensive commodity in the exchange market of human evolution.[4] One could certainly hypothesize that growing our expensive neural tissue must have happened for a good reason, but before we even begin to calculate what humanity gained from this extra neural tissue, we need to recognize that those exchange energetic networks are far too dynamic and complex to be expressed as simple correlations of increased hominid brain size with social complexity like the social brain hypothesis or technology. In other words, given the energetic challenges that a larger, hungry brain poses and how metabolically demanding neural tissue activity can be, when it comes to locating the boundaries of mind very often it pays to abandon our popular intuitions about our big brains as the natural locus of what we refer to as intelligence and instead simply follow the materials and bodies attached to those brains (see also Chemero, 2009, p. 177) when trying to figure out their cognitive ecology and affordances.

What this means very simply is that, when hypothesizing about the possible evolutionary pressures for encephalization, the cost and benefits, the various tradeoffs, and the effects that they have in human life and cognitive evolution, we need to recognize their plastic qualities and situated character. This is rarely an intracranial affair that takes place inside us; rather, it is invariably an extracranial affair that incorporates material and bodily techniques realized in developmental time and social space.

Conclusion

Notwithstanding its long history in the philosophy of mind, the relationship between mind and body, also known as the mind–body problem, is also implicit in the archaeology of mind, constantly challenging our ways of thinking about cognitive evolution. Although the substance dualism between an immaterial mind and a material body has long been rejected, elements of the Cartesian doctrine are still visible. Within cognitive archaeology, the dominant reductionist picture of cognitive explanation remains one that renders ontological supremacy to the brain and seeks to account for the observed changes in size, shape, and neural complexity by means of their possible material and behavioral correlates as these can be found in the archaeological record.

Moreover, cognitive archaeology is often understood as the study of the long-term changes in the capacity of the brain to build, store, and manipulate "inner" or "mental" representations of an "external" material world. Put simply, observed changes in the material record are simply seen as potential indirect sources of information about cognitive changes and processes performed solely in the head. Computational formal psychological models are extensively used to account for those changes in human cognitive evolution. Since most archaeologists are not familiar with the underlying representational assumptions of the models they borrow from psychology and cognitive science, they commit their accounts, without even noticing, to classical disembodied internalism.

Meanwhile, as we saw, many proponents of the embodied cognition approach (including extended mind theorists) argue for an extension of the organismic or biological boundaries of the *res cogitans* rather than for the dissolution of those boundaries altogether. This new kind of *embodied cognitivism* (Malafouris, 2013) leaves materiality external and epiphenomenal to the cognitive system proper. Especially in cognitive archaeology, this tendency can be seen both in the way the concept of embodiment and EC has been used and abused in the conventional narratives of cognitive modernity and in the way that those notions are being misrepresented as compatible with neo-Darwinian approaches. Similarly, notions of "modernity," "information," "adaptation," and "representation" adopted from evolutionary and computational psychology are incompatible with embodied cognitive science and thus should be carefully redefined or abandoned.

Embodiment, at least in the sense that matters to cognitive archaeology and is consistent with theoretical principles of MET, comes with the price of continuity between cognition and material culture or else between cognition, perception, and mediated bodily action. The implications of this continuity are not well understood in archaeology or even cognitive science. One implication, for instance, is that it contradicts the very grounding premises of evolutionary psychology, which has been defined on the basis of—and is still dominated by—a nativist program based on a modular division of the mind between, on one hand, domain-specific perceptual and motor processes and, on the other hand, general-purpose cognitive processes characteristic of human thought (Fodor, 1983). More recently, a number of alternative "neo-evolutionary" models have been developed that emphasize different structuring factors in the evolution of human mind such as the role of cultural inheritance and culturally transmitted variation, the importance of cultural learning, developmental plasticity, and niche construction (Jablonka & Lamb, 2005; Laland, 2000; Richerson & Boyd, 2008; Sterelny, 2003). Although some of those approaches, by adopting a more interactive and externalist outlook, have been very successful in pointing out the importance of development, niche construction, and dynamic co-evolution they retain still much of the basic neo-Darwinian logic of the adaptationist program. As a result, I doubt that the recent call for extending the "neo-evolutionary" synthesis is the way forward in attempting to understand human cognitive evolution. In any case, from the perspective of MET and embodied cognitive science, I suggest that what ECA needs is not a different version of the neo-Darwinian representational logic but instead a more radical post-Darwinian enactive conceptualization. Of course, that is more easily said than done:[5]

> Part of the difficulty in moving beyond the adaptationist framework is to determine what to do after we abandon the idea of natural selection as the main explanation, so that every structure, mechanism, trait, or

> disposition cannot be explained away by its contribution to survival value. The temptation is to say, But then are things there for no reason at all? The task in evolutionary biology is to *change the logical geography of the debate* by studying the tangled, circular relations of congruence among the items to be explained. (Varela et al., 1991, p. 195; emphasis added)

Seen in this light, the meaning of EC in the context of MET is not signifying a simple shift from the disembodied computational image of mind to one that is now grounded in neural structures and brain networks. It is also not associated with a view of the mind as existing within the body' interior. Rather, it signifies that the details of embodiment and thus of action, situation, and mediation matter. Embodiment is the precondition for material engagement and vice versa. Taken together, the two processes explain the dynamical nature and variety of forms that human mental processes can take and how they connect to the world they are about. Thus, it no longer makes any sense to separate an "inner" domain of mentality from an "outer" domain of materiality. Rather, cognition involves and emerges from situated dynamic interactions between different types of materials and activities. It is also important not to confuse symmetry for equality. The fact that a variety of material extraneural resources (bodily, artifactual, or semiotic) contribute to human cognition also implies that, given the unique properties of each material resource, they will make a separate and distinct contribution. Embodiment is what brings those diverse resources and their properties together to form what we define as the human mind.

For all those reasons, embodiment demands a different approach, one sensitive to all those experiential, ecological, and phenomenological dimensions that are very hard to elucidate on the basis of archaeological data. Those questions are important not because we can answer them; instead, they are important because they remind us—not just archaeology but the broader community of cognitive science—how little we know still about the cognitive ecologies of human becoming. This epistemic awareness is important for two main reasons: first, it protects cognitive archaeology from the ghosts of "modernity"; and, second, it opens the way for a thorough redefinition of the archaeology of mind as a field of comparative critical discourse on human becoming. Cognitive archaeology is about the past as much as it is an archaeology of mind in the present. This is not because past and present minds are the same but because they are different. However, this variability preserves sufficient elements of continuity to be comparable. I am not talking about genetic or Darwinian continuities here but instead of developmental continuities of embodiment, action, and material engagement. This is also why, I have come to believe, the archaeology of mind is not the study of how we became human; instead, it is the study of *human becoming*. The former implies that being human is a stage we reached in the past. The latter, in contrast, speaks of an ongoing process that extends very much into the present. I contend that the human mind is precisely that: *becoming*. The mind is not a product but a process (Gosden & Malafouris, 2015; Malafouris, 2015; Malafouris & Renfrew, 2010). The only sense in which popular notions like that of the "psychic unity" of humankind could be retained is if, contrary to their current use, they explicitly refer to the only true universal of human nature and the human mind—its continual openness to change and alterability by incorporating new means of material engagement (see also Wheeler & Clark, 2008). To understand how human beings came to think in the ways that they do, we need a comparative anthropology of what Richard Sennett (2008) in his book *The Craftsman* describes as "material consciousness." I call it "tectonoetic awareness" (Malafouris, 2008*b*). This is the kind of consciousness that archaeologists can excavate.

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Notes

1. As Varela et al. (1991) well pointed out: "Baldly stated, representationalism in cognitive science is the precise homologue of adaptationism in evolutionary theory, for optimality plays the same central role in each domain" (p. 194).
2. Michael Corballis (2003, 2009) has made a strong case for the evolution of language as a gestural system evolving from the so-called mirror system in the primate brain.
3. As Pouw et al. (2014) rightly observe: "current perspectives on gestures are still *disembodied* and too *internalistic* because they seem to implicitly reduce gestures to *cognitively trivial* bodily outputs of (sensorimotor) neural precursors" (emphasis in original, 2014, p. 1).
4. One famous early example of such an exchange is the shrinking of the gut in return for a larger brain (Aiello & Wheeler 1995; Allen 2009).
5. The paradox is that the moment you become truly un-Cartesian you can be accused of being anti-Darwinian.

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5

Materiality and Numerical Cognition

A Material Engagement Theory Perspective

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Introduction

Material engagement theory (MET) envisions materiality as an integral part of cognition (Malafouris, 2013). This is similar to the idea that perception involves not only processing in auditory and association cortex, but also sound waves striking the eardrum and something in the world producing noise; MET, however, assumes greater interactivity and bidirectional change between brains and materiality both over short- and long-term time spans than is characteristic of the causal linkage of audition. Viewing materiality in this way necessarily redraws the boundaries of cognition: it is no longer something performed by the brain alone, but a system that includes the body and the environment, including material culture. This is not the view of mainstream neuroscience, which intently focuses on the brain, has just begun to recognize the contribution of the body, and has seemingly not yet realized that materiality has a constitutive role. This focus is reasonable, given the investigative methodologies currently available and the need to formulate testable hypotheses and limit potential confounds. Nor is it certain that materiality is constitutive of cognition, thus calling its inclusion in cognition into question, as Malafouris (2013) readily admits. Nonetheless, as Malafouris also suggests, seeing cognition through MET's paradigmatic lens—considering it in terms of nontraditional boundaries—has the potential to yield new insights into how humans think, as the present review will argue.

Taking the perspective that cognition is a complex system that includes not only brain but body and materiality provides an apt framework for examining numerical cognition because all three contribute to it, albeit each in different ways. This functionality will be viewed through Malafouris's three central tenets: first, cognition is *embodied and extended*. That is, in addition to the brain, the body and materiality not only contribute to but are constitutive of cognition. This positions the body and materiality as meaningful parts of numerical cognition while preserving the brain's unambiguous and important role. It also provides a basis for comparing the numerical cognition of ancient and existing peoples, particularly through the material and behavioral components. Second, in shaping behavior and psychological responses, materiality has *agency*: it influences the other components of cognition through its properties (or affordances, described further below), thereby shaping numerical system outcomes. This suggests that the materials used to realize and represent numbers have a particular influence on the way we conceptualize them. Finally, materiality has a semiotic function (or a meaning potential), making it an *enactive sign*. This is important in numerical cognition, where material meaning precedes language for numbers, and change in material form changes how numbers are conceptualized.

These central tenets are then applied to representational artifacts used as counting technologies: the fingers, tallies, and strings, suggested by the hand stencils, notched bones, and beads of the Upper Paleolithic and Middle Stone Age. Considering these artifacts as the material component of numerical cognition allows us to interpret them in terms of potential functions, properties, and signification, thus yielding new insights into how ancient peoples may have thought about numbers.

The Mind Is Extended

The idea that the brain is not all there is to cognition is a philosophical perspective known as the *extended mind hypothesis*. It is important to clarify that seeing cognition as extended beyond the body does not entail that the brain is uninvolved or unimportant; rather, the brain is a vital part of a complex, dynamic system that also includes the body and materiality. As an illustration, writing a note to assist memory performs the same function as remembering without material assistance. Because they are functionally indistinct, the standard by which the second is deemed cognitive whereas the first is excluded can be questioned (Clark, 2008; Clark & Chalmers, 1998). And, once paper, pen, or the iPhone Notes application and acts of writing and reading have been admitted into the human memory system, the definition of cognition has necessarily been expanded from something performed by the brain alone to something encompassing material devices and the activities of interacting with them (Estany & Martínez, 2014; Malafouris, 2013). This is not to say that brain, body, and materiality play the same role within the cognitive system; rather, they are seen as contributing in different but complementary and mutually interacting ways.

The new boundaries position material culture as an integral part of cognition, not merely its byproduct, assistant, external repository, or source of information over which its computations might range. Once material culture is viewed as part of a larger cognitive system, insights about the functionality of material culture within the system follow, as do insights about how our brains have evolved to exploit material structures. For example, the material environment, broadly speaking, consists of social institutions, cultural practices, and material artifacts. These help us decompose problems into smaller tasks that are more easily solved because they are smaller (Beer, 2003). This effect is seen in numbers when a complex task like multiplying 8,912 by 7,252 can be reduced to "a series of simpler problems beginning with 2 × 2" (Hodder, 2012, p. 35). Decomposing problems also makes it easier for multiple individuals to collaborate in solutions, thus opening up new possibilities for outcomes in addition to the variation gained through "difference, localism, and choice" (Robson, 2008, p. xxii). Solutions can take the form of artifacts, making them available to other individuals and future generations; this opens up further opportunities to refine or apply artifacts to new uses, thus affording additional possibilities for change (Damerow, 2010).

When material culture enables future individuals to perform tasks and solve new problems, cognitive effort becomes distributed over space and time, an extensionality that is one of the major differences in the use of materiality by the human species (Hutchins, 1995). For example, the calculator represents inventions of numbers, notations, algorithms, mathematical pedagogy, metallurgy, plastics, electronics, software, data storage, marketing, transportation, and so on, an amount of cognitive effort that no one individual or society could easily formulate and synthesize. Someone using a calculator to perform a mathematical task today is unlikely to be any of the people who invented the things that went into the device, which instantiates all sorts of knowledge and makes it available to other individuals as a resource for performing tasks and discovering new applications. That is, someone with a slide rule need not reinvent calculus; she need merely apply the device's ability to manipulate numbers to the problem at hand.

Cumulatively, processes of invention, learning, use, refinement, and extension afforded opportunities for both artifacts and brains to change, especially when long spans of time are considered. Artifactual designs are refined and extended to become more efficient, capable, and tailored to support new or increasingly specialized cultural purposes, while brain functions become repurposed for cultural inventions (e.g., object recognition in literacy; see Perfetti & Tan, 2013). Over even longer spans of time, new brain functions or regions may come into being (e.g., regions of the human intraparietal sulcus specialized for detailed vision; see Orban et al., 2006). Modern calculation devices instantiate, in a very meaningful sense, much of this ancestral cognitive activity: electronic calculators are not invented *ex nihilo* but rather from the number concepts, numerical algorithms, and notations; supporting technologies; and repurposed brain functions realized through the past and present interactions, interdependencies, and multidirectional changes of brains, bodies, and materiality.

Understanding how the incorporation of materiality into the human cognitive system and its interaction with brains and bodies might have led to the realization of number concepts requires insight into the unique expansion of the parietal lobe in *Homo sapiens* and its consequences, including globularization, reorganization of neural connectivity between and within various brain regions, and enhanced parietal functioning (Bruner, 2004, 2010, 2014; Bruner et al., 2014; Bruner, Manzi, & Arsuaga, 2003; Coolidge & Overmann, 2012; Coolidge, Wynn, Overmann, & Hicks, 2015). Cognitive functions likely enhanced by the morphometric rescaling of the parietal lobe include analytical abilities for relationships of space, time, and number; multimodal association of visuospatial and other sensory information; motor sequence planning and execution; the ability to "know" and control the fingers; internal representations (to whatever degree such exist) of external space; and abilities for understanding concepts through associations with embodied experience (i.e., metaphor).

As previously noted, regions in the human intraparietal sulcus (a portion of the parietal lobe located on its lateral surface that is not present in the brains of macaques) represent additional aspects of dimensionality in shape, and this detailed vision, in conjunction with fine motor control of the fingers, might have informed our ability to make and use tools, especially those with compound or moving parts (Orban & Caruana, 2014; Orban et al., 2006). However, it is also possible that the new intraparietal regions were the result of long-term interaction with tools, an activity-dependent change in neural function known as metaplasticity because the use of tools by the hominid lineage extends more than 2.5 million years. Even more likely is the possibility that it was—and still is because human becoming is hardly finished—the interaction between tools and brains that changed the form and function of both, alterations detectible especially when viewed over long spans of time.

The interaction between parietal functions for quantity perception (numerosity, which is shared by many species) and the fingers (finger gnosia, the ability to know the fingers; haptic perception, the sense of active touch; and neural reactions to tools and graspable objects) may inform another unique human capability: engaging materiality with the fingers may have allowed us to express our innate, alinguistic quantity perception in material form, making numerical properties tangible, visible, and manipulable and thereby bridging the mental and physical senses of quantity and facilitating the formation of explicit concepts of number (Coolidge & Overmann, 2012; Malafouris, 2010). Few species use their paws, hooves, or pads to explore and gain information about the world (Gallagher, 2013). The unique capabilities of the hand that enable us to use it for these purposes are consistent with the amount of our sensorimotor cortex dedicated to its sensation and control (Penfield & Jasper, 1954). Without the ability to engage materiality with our hands and fingers, our quantity appreciation might otherwise have remained locked within the limits of our perceptual experience of quantity.[1] More severely, a lack of material engagement might also have precluded us from forming explicit concepts of even small quantities salient within the subitizing range because the tactile manipulation of objects and reference sets appears integral to the process of realizing higher order relations of shared cardinality for both subitizable and larger numbers (Overmann, 2015*a*). The engagement of materiality by brains and bodies is thus vital, the very mechanism by which our numerosity becomes human numerical cognition.

Materiality Has Agency

The second tenet of MET is the idea that materiality has agency, the capacity of an agent to act in the world (Malafouris, 2013). Agency is often conceptualized as something humans have related to their abilities to form and pursue courses of action (sometimes called *free will* and often connoting intentionality). However, agency can also be understood as a relational property, something that causes change within a system; thus, material artifacts, in changing human behavior, display agency. Thus, an agent need not be alive in order to act. For example, a speed bump insists that drivers slow down or risk car damage and the attendant need for repairs (Malafouris, 2013). But material agency is no mere passive repository of human intentionality, like that of the fellows who design and install speed bumps to moderate or penalize driving behavior. A stone has agency in producing (or not) a sharp, usable edge, thus making it suitable (or not) for producing a handaxe and affecting outcomes of activities like hunting and informing decisions about whether a group returns to its source area; a totem has agency in enforcing taboos, altering beliefs and behavior in those who acknowledge its power (Gell, 1998); the sextant has agency in enabling sailors to estimate latitude and longitude, thus improving their chances of reaching their desired destination (Hutchins, 1995). Although neither equivalent to nor interchangeable with human agency, material agency is nonetheless complementary and relationally intertwined with human agency to the extent that it can be difficult to separate the two in any meaningful sense (Knappett, 2005).

Whereas materiality has agency in being able to change numerical cognition, the specific change it is able to effect is a function of its *affordances*. As theorized by psychologist James Gibson, affordances are what the environment offers to an agent, and they are found in the interaction between an agent's abilities and its environment, rather than being properties of either. Affordances are inherently related to an agent's abilities, both physical and mental; if a species lacks the ability to exploit a particular affordance, that affordance is not one for that species (Gibson, 1977, 1979). A monkey, for example, has little use for a calculator beyond mashing its buttons or using it as a projectile. Such employments undoubtedly fall within the human behavioral repertoire, but humans can also apply calculators to mathematical tasks (and, indeed, might not be able to perform them without the affordances the calculator provides).

The example of the calculator illustrates that affordances are not just features of the natural environment: they can be encoded in material artifacts, making them available for other individuals and generations and distributing cognitive effort geographically and temporally (Hutchins, 1995; Smith, 2007). When solutions to problems and enablers of task performance take the form of artifacts, their capabilities influence behaviors and outcomes in subsequent performances and problem-solving. An example is the sextant, a navigation instrument that instantiates the "kinds of [wayfinding] knowledge that would be exceedingly difficult to represent mentally" (Hutchins, 1995, p. 96). The sextant (as a calculator does for mathematical knowledge) represents navigational knowledge that has been accumulated, changed, and improved by generations of individuals, as well as algorithms implicit in and automated through the artifact's design. Artifactual structures reflect the requirements of the tasks for which they were created, just as their designs complement and compensate for human psychological and anatomical abilities and limitations. Their structures, designs, and capabilities shape and constrain task performance: the sextant entails that navigation involves measuring celestial altitudes; the calculator solves square roots when buttons that activate preformed algorithms are pressed in certain combinations. Such devices can also offer different and perhaps new possibilities for action, thus expanding the range of potential outcomes.

What do material agency and affordances look like in numerical cognition? Answering this requires us first to consider what numbers and numerical cognition are: numbers are concepts of discrete quantity like "one," "two," and "three" and the relations between them. Numerical relations are manipulated by arithmetical operations like addition and subtraction. Numerical cognition is thinking with numbers, a characterization that is not intended to limit its scope to numeracy or reasoning with numbers, but rather to include the process by which number concepts are realized through the interaction of brains, bodies, and materiality, a model of which is proposed in Figure 5.1. Simply, numerical concepts and words like "one," "two," and "three" result from the interaction of the perceptual system for quantity, the fingers, and material objects. As materiality—both the body and artifacts—is incorporated into the cognitive system for numbers, the innate sense of quantity that is common to many species is given opportunities for explication and elaboration in a way unique to humans. Tangibility yields structure and stability and (depending on the materiality that comprises the artifact) a certain amount of manipulability for the quantity instantiated. Once explicit, quantity also becomes discrete, and its material form gives it persistence. These qualities increase the likelihood that

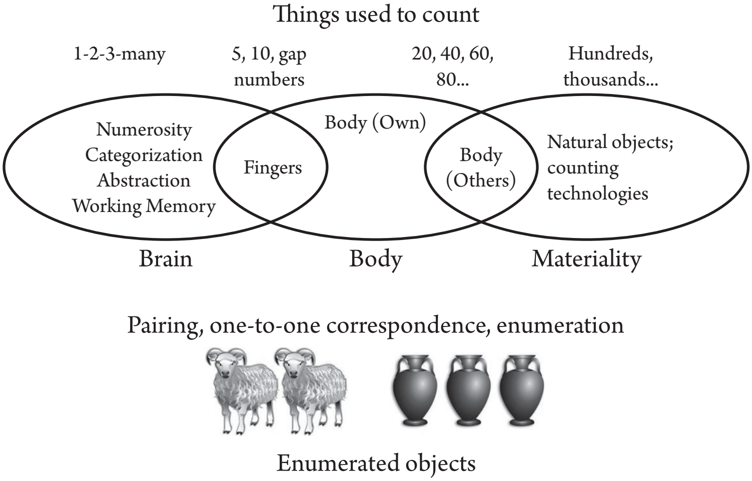

Figure 5.1. Conceptual model of counting in numerical cognition, based on the neuroscience of number, ethnographic observations about the use of the body and material devices for counting, linguistic data about characteristics that number words share across languages, and ideas about how the components contribute and interact when considered through Material Engagement Theory. The model is not reflective of any particular society or culture and should not be understood as implying either progress or linearity, but rather the typical changes that occur as materiality is incorporated into numerical cognition. Images from OpenClipArt.com.

Components include brain (left), body (middle), and materiality (right). The brain supports functions such as numerosity and categorization, while the body provides fingers that interact with the brain and materiality through processes like finger gnosia, haptic perception, and neural reactions to tools and graspable objects. Materiality includes both naturally occurring objects used as reference sets and artifacts made for counting—respectively, things like fingers and notched sticks. Brain, body, and materiality overlap to characterize their interactivity and because brains do not occur in a vat, nor bodies in a vacuum.

The model differentiates things used to count (top) from enumerated objects (bottom), with relations between the two achieved through strategies such as pairing (a behavior within the capabilities of non-human primates; see Conway & Christiansen, 2001; Fragaszy, Galloway, Johnson-Pynn, & Brakke, 2002) and one-to-one correspondence (behavior unique to humans). Highest number counted is related to the things used to count; it increases as materiality is incorporated into the system through the changes that result from the interaction of material affordances and agent abilities.

Number system characteristics suggest their origins. Initial quantity expressions are generally "one", "two", "three", "big many" and "small many" (Menninger, 1992), which are consistent with the neurological constraints on quantity perception and attention. Involvement of the body leaves traces in the form of anatomic bases (e.g., decimal) and embodied vocabulary like the word 'digit' (Comrie, 2013). Material devices used as counting technologies are not necessarily limited to 'three' or anatomically patterned; their characteristic signature is the extension of highest number counted.

someone interacting with the artifact will notice similarities and patterns in the quantity it instantiates, like each notch being one more than the notch it follows. Patterns and similarities, in turn, can be codified and thus endure in the form of artifacts and language.

Different counting technologies offer different affordances, each of which shapes or constrains the resultant quantification behavior and numerical system outcomes in different ways. The use of the fingers for counting, for example, appears to be cross-culturally universal, independent of how elaborate a culture's number system might be. This behavior reflects the neurological interaction between the perceptual system for quantity and control of the fingers (reviewed in Overmann, 2014). Because the fingers interact with materiality and are literally ready to hand, they bridge psychological capabilities like numerosity with material objects that have quantity. They are also typically the first things used as a reference in counting: they instantiate the concept of quantity, making it accessible and communicable. In addition to being found in emerging number systems, finger-counting persists in highly elaborated ones as well, where it acts as a convenient materiality for enumeration and an aid to memory, likely because of the neurological interaction between numerosity and control of the fingers (i.e., between the intraparietal sulcus and angular gyrus). In comparison, beads can also be used as a counting technology, have a comparable cross-cultural prevalence, and similarly span the full spectrum of numerical elaboration. For example, the rosary requires neither concepts of nor words for numbers, whereas beads have been used to count into the tens of thousands by the North American people known as the Pomo (Barrett, 1952). However, many societies make and wear beads, but few count with them, an uneven ratio that perhaps reflects the need to repurpose beads from ornamentation to quantification and the lack of a specific neurological function integrating the material form with numerosity. Fingers and beads also have different capacities for quantity: fingers are generally (but not invariably) limited to low numbers, whereas beads (as attested by Pomo counting) have a much greater potential.

A similar differential is found in material capacities for instantiating relations between numbers. Accumulation is something that all early counting technologies appear to have in common: it is easy to extend another finger or add another notch to a tally, knot a string, add a stone to a pile, or mark the ground—at least up to the capacity of the material form: the number of fingers, the surface area for adding notches, the length of string to be knotted, and so on. Fewer of these technologies have a ready potential for subtraction, however. Notches are difficult to fill in, although knots can be untied, stones removed, and marks on the ground erased. Fingers, despite their universality in counting, are seemingly not a factor in developing subtraction (or it might be developed sooner), perhaps because the embodied experience of quantity does not disappear when an extended finger is flexed in the same way that it does when, for example, a stone is removed from the pile. Given the potential of material counting technologies for accumulation (all) and subtraction (some), it cannot be coincidental that addition is generally the first arithmetical operation to emerge, with subtraction developing later.

Regularity, manipulability, and integrity are other characteristics in which material affordances differ. Notches on sticks and knots in strings instantiate the kind of stable-order linearity that fingers afford, a similarity that is perhaps a factor in why such technologies tend to follow finger-counting. By comparison, stones and other noncontiguous objects lack implicit order, but their individual elements can be manipulated in ways that notches, knots, and fingers cannot. Greater manipulability is a likely factor in extending the recognition of numerical relations beyond plus-one. Four pebbles, for example, can be decomposed and rearranged as "three" and "one," "one" and "three," or "two" and "two," groupings with the potential to illuminate not only the quantity relations involved but their relative equality (i.e., "two" and "two" balance in a way that "three" and "one" do not). A notched tally, however, maintains its integrity as an instantiated quantity in a way that loose, manipulable counters do not unless they are somehow contained. As these examples serve to illustrate, potential outcomes for numerical elaboration may be enabled or constrained by the affordances of particular material forms (Hodder, 2012; Knappett, 2005), just as affordance differences may be potential factors in the incorporation of new material forms. Material agency and the variability admitted through affordance differences may be as significant in influencing numerical system outcomes as the various decisions, applications, and values of the social dimension.

The psychological functioning of the brain changes as the cognitive system for numbers incorporates materiality. Although parietal functions such as numerosity and finger control are significant to the realization of initial discrete quantities, arithmetical and mathematical tasks additionally engage the frontal lobe and executive functions such as intentionality and working memory (Zamarian, Ischebeck, & Delazer, 2009), thus increasing goal-directed behavior. Demands on various forms of memory may decrease: spatial memory (memory for object location used as a heuristic in societies with few numbers; e.g., Butterworth & Reeve, 2008), working memory, and visuospatial working memory (a component of working memory that supports mental imagery). Reduced demands on memory, along with the visualization and problem-solving facilitated by material engagement, allow freed attentional capacity to be repurposed to things like pattern recognition, categorization, and abstraction, thus enabling the formation of new concepts. At the same time, interaction with material linearity increases the linearity of the mental number line, an internal resource for estimating numerical magnitudes (Brannon, 2006; Fischer, 2008; Previtali, Rinaldi, & Girelli, 2011), and this may assist the realization of higher quantities in regularized and productive ways.

The numerical system also changes: highest number counted goes up as materiality is incorporated; this seems only commonsensical, given that material devices for counting seem like just the very thing to help us count. An increase in highest number counted, in turn, affords an increased likelihood that the relations between numbers will be discovered (this is simply a function of exemplar availability; see Beller & Bender, 2011) and codified in the form of devices, algorithms, and language. As numbers become more elaborated, they become more useful, a utility that makes them familiar and habitual. This positions them as a cognitive technology, a body of knowledge that structures understanding and behavior (De Cruz, 2008, 2012). The more familiar and habitual a cognitive technology becomes, the more likely it is that it will be extended to new domains (Overmann, 2013) and become entangled in cultural practices and behaviors (Hodder, 2012). The more ingrained in culture numbers become, the more likely they are to be elaborated; their usefulness may intensify the need to develop and extend them.

Material Signs Are Enactive

The third tenet of MET is enactive signification, the idea that things acquire meaning in virtue of what they are and what we do with them. Integral to enactive signification is the material sign, which functions semiotically in a manner quite different from that of the linguistic sign. Where a word is ephemeral—speak it, and it is just as quickly gone—the material sign persists; where a string of words occur in a linear sequence, a function of sound production in language, the material sign has no obvious start or stop (Malafouris, 2013). Linguistic signs are communicative and symbolic, denoting quantity through arbitrary conventions, while material signs are enactive and instantiate quantity by simply being what they are (Malafouris, 2013), objects of a certain quantity in interaction with numerosity and perhaps the fingers. Language and the linguistic signs that comprise it have been said to form a "longer, slower, and more complex" bridge between communication and cognition, implying that "things, concepts of things, and signs of concepts of things" may constitute a shorter, faster, simpler bridge, one that is more directly connected to thinking (Brandt, 2010, p. 253), including numerical thinking. Essentially, both are critical to accessing numerical cognition and elaborating numerical intuitions into number systems; however, they differ in more than the speed of the bridge they provide (i.e., in things like their semiotic function, as discussed later), and any account of numerical cognition that does not consider both is necessarily incomplete.

The semiotic differentiae illuminate some differences in the roles of material and linguistic signs in the development of number concepts. By instantiating discrete quantities, the material sign (a term encompassing material counting technologies, including the body) anchors and stabilizes them, facilitating the realization of explicit number concepts and their interrelations (Coolidge & Overmann, 2012; Hutchins, 2005; Malafouris, 2010). Materiality (and forms of numerical notation as well, as will be discussed) enable the manipulation of numerical relations and algorithms in ways that language does not (Sfard & Linchevski, 1994). Simply, language, counting devices, and numerical notations represent numbers differently (as attested by the different universal properties of language for numbers and numerical notations [Chrisomalis, 2010; Greenberg, 1978] and the fact that neither considers the properties of non-notational material forms). Algebraic problems in the form of spoken narratives are difficult to solve, a challenge not resolved by writing the language phonographically. Material structures and numerical notations, by comparison, enable a more direct manipulation of the logical and spatial relationships that are the essence of numerical cognition and mathematics. However, if language is a "slow and hesitant" route to numerical cognition (Sfard & Linchevski, 1994, p. 198), linguistic signs nonetheless enable numerical concepts to be communicated, learned, and applied in social contexts in ways not possible through visuospatial means alone (Ferrari, 2003). Furthermore, lexicalization may help number concepts become conceptualized as entities in their own right, allowing them to acquire new properties (as stabilized and represented by material realizers) and become available to be acted upon by new operations and processes.

Numerosity (the perceptual system for quantity shared with other species) and language (which is not shared) are both essential to numeracy (earlier defined as the ability to reason with numbers). Language per se, however, is insufficient for developing number concepts, or there would be no languages that lack them, as the Pirahã language spoken in Amazonian Brazil famously does (e.g., Everett, 2005). As cognitive functions, numeracy (which depends on numerosity) and language are independent in that they are doubly dissociable (Brannon, 2005). That is, a person can lose the ability to calculate but retain the ability to converse, and vice versa (Ardila & Rosselli, 2002; Varley, Klessinger, Romanowski, & Siegal, 2005). Independence is also suggested by the multiplicity of species with numerosity but lacking language and the fact that human infants demonstrate the ability to appreciate quantity before they develop language (e.g., Cantlon, Brannon, Carter, & Pelphrey, 2006; Van Marle & Wynn, 2011). Furthermore, material signs precede linguistic signs in ethnographic accounts of initial quantification (e.g., Chagnon, 2013; da Silva, 1962; Karsten, 1935; Murphy & Quain, 1955; Staden, 1928; Turrado Moreno, 1945), and material and linguistic signs differ semiotically. These differences suggest that materiality and language be analyzed both separately and in interaction with each other for their contributions to numerical cognition.

Material and Linguistic Signs

An initial analysis of the semiotic differences of materiality and language is shown in Table 5.1. The basic systems (material objects and non-numerical speech) appear in the outermost columns and are related as signified and signifier (i.e., the concept *jar* and the word "jar," or, in Peircean terms, *interpretant* and *representatem*; Gottdiener, 1995). From the left toward the middle, the order reflects increasing elaboration in material signs for numbers: material objects (jars), counting technologies (e.g., tallies or tokens), and cumulative and ciphered numerical notations[2] (respectively, the Roman numeral III and the Hindu–Arabic numeral 3). From the right toward the middle, the order reflects increasing elaboration in linguistic signs for numbers: non-numerical language ("jar"), emergent adjectival number terms ("threeness"), full-fledged lexical terms for numbers ("three"), and phonographically written numbers (three).[3]

The semiotic qualities considered in the analysis included type (metrological, related through properties of capacity and weight; numerical, denoting quantity; and non-numerical), sense mode (tactile, visual, or auditory), persistence (durable or ephemeral), sequentiality (no start/stop or linear), logic (enactive or communicative), and representation (instantiate or symbolize). Composition (metrological, quantitative, or grammatical) examined syntactic structure in larger combinations; decomposition (metrological, quantitative, phonemic, or meaningless) explored the meaning of individual elements when separated from a larger group. Finally, conventionality and language (low, medium, or high) examined the amount of cultural or linguistic knowledge required to understand meaning (Houston, 1994).

The basic systems (material objects and non-numerical speech) had no qualities in common despite their signifier–signified relation. Systems adjacent to the basic ones were similar to them in terms of the semiotic qualities considered; as systems became elaborated (with ciphered and phonographic notations containing the greatest mix of semiotic qualities from the two basic systems), they adopted more of the qualities belonging to the other basic system. Such hybridization is presumably incremental and nonlinear, and it depends on the extensive interaction and interdependence of materiality and language (i.e., their interaction and interdependence comprise the mechanism that enables their elaboration). It also seems reasonable to conjecture that not all qualities would be equally changeable (thus, not all transitions would represent change of the same magnitude) and that few transitions likely represent deliberate, consciously thought-through change (though these would not be excluded) but rather combinations of extended usage, discovery, happenstance, and mistakes, and the contributions of many individuals.

Table 5.1 **Comparison of Materiality, Notational Numbers, and Speech**

Quality	***Material***		***Numerical Notation***			***Speech***		
	Object	**Sign**	**Cumulative**	**Ciphered**	**Phonographic**	**Lexical Nr.**	**Adjective**	**Noun**
Example		● ● ●	III	3	three	‘three’	‘-ness’	‘jar’
Type	Metrological	Numerical	Numerical	Numerical	Numerical	Numerical	Numerical	Non-Numeric
Sense Mode	Tactile/visual	Tactile/visual	Visual	Visual	Visual	Auditory	Auditory	Auditory
Persistence	Durable	Durable	Durable	Durable	Durable	Ephemeral	Ephemeral	Ephemeral
Sequentiality	No start/stop	No start/stop	No start/stop	Linear	Linear	Linear	Linear	Linear
Logic	Enactive	Enactive	Enactive	Communicative	Communicative	Communicative	Communicative	Communicative
Representation	Instantiate	Instantiate	Instantiate	Symbolize	Symbolize	Symbolize	Symbolize	Symbolize
Composition	Metrological	Quantitative	Quantitative	Quantitative	Qty. or gram.	Qty. or gram.	Grammatical	Grammatical
Decomposition	Metrological	Quantitative	Quantitative	Meaningless	Phonemic	Phonemic	Phonemic	Phonemic
Conventionality	Low	Low	Low	Medium	Medium	High	High	High
Language	Low	Low	Low	Medium	Medium	High	High	High

Note: Comparison of type, sense mode, semiotic function (persistence, sequentiality, logic, and representation), composition–decomposition, and amount of cultural–linguistic knowledge needed to understand meaning (conventionality and language) in material objects and signs, numerical notations (cumulative, ciphered, and phonographic), and speech (lexical numbers, emerging adjectival quantity terms, and non-numerical language). Developed from concepts in Chrisomalis, 2010 (numerical notations and lexical numbers); Houston, 1994 (conventionality and language); and Malafouris, 2013 (semiotic functions of material and linguistic signs). Material objects and non-numerical spoken language appear in the outer columns with no qualities in common, though they are related through reference (as the word ‘jar’ refers to the object jar). The other systems generally share qualities with one or more of the basic systems.

Objects, counting technologies, and cumulative notations share most characteristics; the only difference is that objects can be related metrologically (through characteristics of capacity, weight, size, measure, etc.), and objects and counting technologies are perhaps more tactile than written notations. Ciphered notations share several characteristics with material objects and counting technologies. These similarities perhaps explain why material instantiations of quantity and numerical notations are recognized translinguistically, making them highly likely to diffuse across linguistic and cultural boundaries and generally the first thing to be recognized in unknown scripts.

Overall, language and materiality interact in ways that contribute to the development of numerical cognition. Language provides an access that is critical to explicating and elaborating numerical concepts in material form, and it absorbs material characteristics like the productive cycles that structure numerical systems (e.g., decimal, quinary/vigesimal, etc.). Materiality provides the stability, anchoring, and representation that are critical to realizing and expressing numerical concepts in language, and it structures numerical thinking (e.g., linearity, stable order, etc.).

Material and Linguistic Affordances

Additional differences are found in the affordances that material and linguistic signs offer to numerical cognition. Linguistic signs for quantity are arranged in ordinal sequences (e.g., "one, two, three. . ."), and the enumeration enabled by ordinal sequencing can facilitate the bundling of material signs for quantity (e.g., in which six or ten units of a smaller quantity equal and are exchanged for one unit of a larger quantity[4]). Material signs for quantity can also be rearranged and decomposed (to the degree permitted by the material form, as previously noted), thus enabling access to the individual elements and their various permutations in a way that linguistic signs do not permit. There is no way to get inside the spoken word "four" to understand "two plus two," let alone "ten minus six," "twenty divided by five," "square root of sixteen," or indeed any of the infinity of possible relations. The modern reader may understand these relations as implicit in the definitions of the ordinal numbers, but, in actuality, such relations and algorithms are unknown until they have been explicated and codified, including their general extensibility ("–1,365,788 divided by –341,447," for example, also equals "four"). In such explication and extension, materiality is critical to visualizing and stabilizing numerical concepts in symbolic form, and the example illustrates the observation of archaeologist Colin Renfrew regarding its role: "the symbol cannot exist without the substance, and the material reality of the substance precedes the symbolic role" (Renfrew, 2004, p. 23).

Where the affordances of materiality and language coincide, there may be an increased potential for long-term stability of the numerical system. For example, peoples in Papua New Guinea count up to 27 using their bodies (Lean, 1992; Saxe, 2012). The material structure used for counting is an ordinal counting sequence, similar to the ordinal counting sequence provided by language. The affordances are mutually reinforcing, so the system is geared toward stability, and, indeed, body-counting systems have a long history in Papua New Guinea (Lean, 1992; Saxe, 2012). Alternatively, where the affordances of materiality and language contrast, there may be an opportunity to notice and analyze the differences to gain insight into the nature of each, thus enabling their exploitation, extension, and elaboration (Beller & Bender, 2011). This is simply the principle that contrast can illuminate differences better than similarities might. However, a differential opportunity for elaboration does not entail that the potential will be realized: any potential for elaboration is still subject to cultural needs and priorities. No matter how dissimilar the affordances of material and language might be for analytic comparison, a society that does not need or value numbers will not elaborate them to the same extent as a society that finds them vital to its survival.

Such affordance similarities and differences are neither advantageous nor disadvantageous, merely circumstances that inform numerical system outcomes.

Furthermore, the potential for contrastive difference to afford opportunities for analysis and change is not the only consideration. For example, Chinese lexical and notational numbers share common structuring (i.e., affordance similarities), a circumstance that at least partially explains the mathematical task performance advantages of Chinese speakers relative to English speakers, whose lexical and notational numbers are structured differently (Cantlon & Brannon, 2007; Chrisomalis, 2010). Thus, it is not simply affordance similarities or differences per se, but their holistic interactions with psychological and physical abilities that influence potential outcomes in numerical systems.

Using Material Engagement Theory to Interpret Artifacts

Fingers

In ethnographic descriptions of how modern peoples count, finger-counting is cross-culturally prevalent. Whereas there are neurological reasons that likely explain why finger-counting is ubiquitous (i.e., the interaction between the perceptual system for quantity and the sensory and motor systems controlling the fingers; reviewed in Coolidge & Overmann, 2012), there is an interesting point that should be highlighted: not only is finger-counting seemingly independent of how elaborate the numerical system might be, it spans the full spectrum of numerical system elaboration because it is found both in systems with few numbers and in those with computers and calculus. Moreover, widespread phenomena of embodied vocabulary (words like the English word "digit," which means both "finger" and "number," or numbers such as "seven" composed as "five plus two") and anatomical cycles (decimal, quinary, vigesimal, etc., which characterize most of the world's number systems; see Comrie, 2013) suggest that finger-counting has been fundamental to forming initial number concepts in most—if not all—number systems.

What makes the fingers such an apt material technology for early counting? As was previously mentioned, counting with the fingers may be cognitively prepotent because of the interaction between the parts of the parietal lobe involved in quantity perception and the sensorimotor control of the fingers. The sense of touch is also unique in its bipolarity, having both an external aspect in what the objects we touch feel like, as well as an internal aspect in what we feel when an object touches us (Gallagher, 2013), that may help broker relationships between our psychological processes and our material culture. Counting involves constructing relations between enumerated objects and a reference set, and fingers are literally ready to hand when a reference set is needed. However, when fingers are used as a reference set to form initial concepts of quantity, a more fundamental principle than their mere availability and convenience is in action: their use indicates the judgment of relations between world and body, in which a quality such as size in each is assessed in relation to the other (Gallagher, 2013). Whereas many number systems transition to the use of reference sets that are not embodied, enabling world-to-world comparisons (e.g., a tally as a reference), such need not be the case, as attested by numerical systems based on body-counting (Lean, 1992; Saxe, 2012). Arguably, the distinction between fingers and tallies is not large because the former are as much a material technology as the latter; the difference is the sensory bipolarity that finger-counting entails.

Upper Paleolithic Hand Stencils

Finger-counting may have a fairly deep history if Rouillon (2006) is correct that the 27,000-year-old hand stencils in Cosquer Cave represent integers (also see Overmann, 2014, for a comparison of the hand stencils at Cosquer and Gargas to finger-counting behavior across cultures). When the fingers are used as a material counting technology, their affordances shape the resultant number system: five fingers on two hands impose anatomically based cycles of five and ten onto our number systems. The affordances of the hand mean that we generally start with an outside finger (the thumb or the little finger) and work our way across the fingers sequentially, imposing linearity and stable order (Gelman & Gallistel, 1978). Their limited capacity necessitates repeated use of the same hand for numbers up to five; numbers higher than five generally require the recruitment of other hands or the inclusion of nonembodied materiality with similar affordances (e.g., tallies, which share with fingers the potential for conceptualizations of stable order and the successor function).

Thus, a number system based on finger-counting, were it represented in paint, would use only the finger-patterns involved in sequentially flexing or extending the fingers to form integers, as the ones at Cosquer Cave appear to do (Rouillon, 2006). One hand would be used for the stencils if it counted no higher than five (though this could also be an effect of the production process); it might also underrepresent the number "four," given that "five" tends to emerge first (as scaffolded by the hand entire) after "one," "two," and "three," suggesting "four" later fills in the gap (as scaffolded by the finger sequence). The occurrence of tallies in roughly the same region and time period suggests a numerical system incorporating additional material forms, with the effect of increasing highest number counted.

Beyond Fingers

Aside from the possible occasional recording in paint, finger-counting does not persist, making it a particularly perishable medium; even marks on the ground tend to persist longer than someone is willing to sustain a finger-pattern. Given a social requirement for remembering or communicating quantity over time or distance, some more durable, transportable form may be sought. In body-counting systems, this might take the form of body-paint (something that will not preserve archaeologically, unless it is represented in parietal art or petroglyphs, or indirectly and rather speculatively construed from the presence of ochre); in other systems, material devices might be used. In either case, the capacity for enumeration increases, which has an effect on the number system itself because, as previously mentioned, increased highest number counted increases the discoverability of numerical relations (Beller & Bender, 2011). Discovery of numerical relations or the limits of particular material forms, in turn, may inspire the inclusion of other forms of materiality with different affordances (e.g., manipulability). As was the case when affordances of language and materiality differed, contrastive differences in material forms affordances can serve to scaffold numerical concepts. For example, whereas both fingers and tallies instantiate plus-one stable order, the latter's greater capacity may also suggest a more indefinite accumulation. This is not to say that all such possibilities will be realized (as the Romans apparently failed to recognize the concept of "zero" implicit in their abacus design).

Upper Paleolithic Notched Tallies

Tallies in the form of notched bones are fairly common in the Upper Paleolithic, as for example, the artifacts from Abri Cellier (dated to 28,000 years ago) and Grotte du Taï (14,000 years ago). The older bones are marked by deep cutmarks in a single row, regular in their size (large) and disposition (even) but fairly simple in their representation of quantity (if indeed that was their purpose); by comparison, the younger artifact contains a complex, multirow sequence of small cutmarks, still regular and even but presenting the appearance of a fairly elaborate quantification (Marshack, 1991). If the use for quantification remains ambiguous for the Abri Cellier bones, the potential quantificational purpose of the later Taï plaque seems less so, likely because its similarity to more recent quantificational artifacts and the higher number of its marks lends it a plausible recognizability. However, archaeologists have approached the potential purposes of such artifacts cautiously, justly pointing out that cutmarks can represent, in addition to counting and decoration, things like butchery, record keeping, divination, music, fiber- or leather-working, or other tool use (Reese, 2002).

Disambiguating such purposes has been attempted through various methods. Cutmark surface disposition has been assessed for randomness; patterns deemed more random are associated with butchery, those less haphazard thought to be more intentional and indicative of associated tool use. Microscopic analysis has also been used: wear patterns and trace elements can indicate tool use; cutmark distribution across artifactual surfaces and by time (the latter is

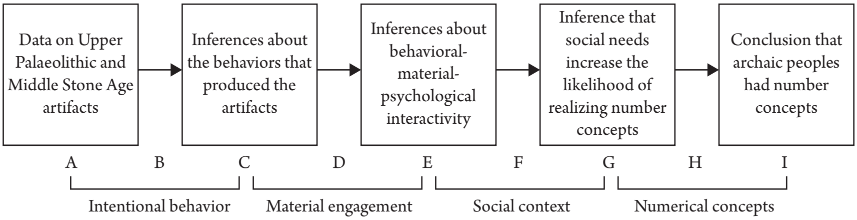

Figure 5.2. Bridging argument for material artifacts possibly used for quantification (modeled after Botha, 2008).

- Intentional behavior inference: From data about Upper Paleolithic and Middle Stone Age artifacts, inferences can be made regarding the behaviors that produced them (e.g., punctures in shells were made by humans rather than caused by animals or natural processes; bone marks were intentionally made rather than occurred inadvertently during butchery; etc.).
- Material engagement inference: From the artifacts and the behaviors that produced them, it can be inferred that either archaic peoples engaged specific material forms in ways that had the potential to generate number concepts, like notching bones (the minimal inference), or they produced material forms that reflected the availability of number concepts, like the hand stencils (the maximal inference).
- Social context inference: From material engagements with the potential to generate number concepts situated in certain social contexts, it can be inferred that social needs increased the likelihood of realizing and elaborating number concepts.
- Numerical concepts inference: From the increased likelihood of realizing numbers in certain social contexts, it can be inferred that Upper Palaeolithic peoples had number concepts and Middle Stone Age peoples may have had numbers (to the degree consistent with the material structures used for possible quantification and social needs for numbers).

assessed by characteristics indicating use of the same or different tools; see d'Errico, 1991) may distinguish decoration from quantification. The benefit of using such techniques is undeniable and an essential first step in inferring whether artifacts were used for quantification (see Figure 5.2), but material engagement must also be considered. That is, notches, even if made for decoration, represent a motor activity that provides an opportunity for the development of skill, and they instantiate the kind of tactile and visual regularities that can scaffold numerical cognition by providing affordances (as previously discussed) that engage psychological processes such as categorization, abstraction, working memory, and language. Behaviors are situated in social contexts that act to increase (or not) the need for numbers as a cognitive technology:

> the elaboration of overall complexity in numeral systems—i.e., the development from highly restricted to generative systems that can name precise quantities into the tens, hundreds, or thousands—is motivated (at least in part) by social and cultural practices that

> encourage counting and/or keeping track of precise quantities. (Epps, Bowerin, Hansen, Hill, & Zentz, 2012, p. 42)

Artifacts such as the Cellier and Taï bones instantiate quantities that can be compared, communicated, and used across time and distance; furthermore, these purposes can be accomplished regardless of the availability of words for numbers or even concepts of the specific quantities represented by the artifacts (though it seems likely that, especially for the Taï plaque, both concepts and words for numbers would have been available to some extent; see Overmann, 2013).

Middle Stone Age Stringed Beads

Beads of marine shells, ostrich eggshell, and stone, many with wear patterns of stringing and some with traces of ochre, have been found at several dozen Middle Stone Age sites throughout Africa and the Near East (covered in detail by Wynn, Overmann, Coolidge, & Janulis, Chapter 9, in this volume), most famously at Blombos Cave in South Africa, where they have been dated to approximately 77,000 years ago (d'Errico, Henshilwood, Vanhaeren, & Van Niekerk, 2005; Henshilwood, d'Errico, Vanhaeren, Van Niekerk, & Jacobs, 2004; Vanhaeren, d'Errico, Van Niekerk, Henshilwood, & Erasmus, 2013). This ubiquity is consistent with the prevalence of beads in existing cultures, as most cultures make beads. Stringed beads, although generally made and used for ornamentation, have affordances that may (in comparison to other artifacts) increase their likelihood of being repurposed from ornamentation to counting. That is, many objects do not have the same potential as beads for being used as an initial counting technology: knives and can openers, for example, have sharp edges and bulky shapes that tend to make them less easily manipulated—less handleable—as the possible elements of a reference set (as differentiated from being enumerated as objects; see Figure 5.1), no matter what quantity relations they might also happen to instantiate when placed in a row.

In addition to their handleability, beads have other affordances that suggest that their use in counting will take similar form across cultures. For example, as beads are slid along a string, they instantiate stable-order, plus-one, accumulative relations and are analogous in this regard to other initial counting technologies like fingers and tallies. Beads can be applied to counting methods that range from extremely complex to fairly simple. Exemplifying the former, the Pomo, who were mentioned previously, used beads to count to impressively high numbers (Barrett, 1952), although such elaborated counting with beads is rarely described in the ethnographic literature, suggesting it is unusual. A fairly simple counting method, one-to-one correspondence, is much more typical; moreover, it requires neither concepts of nor vocabulary for numbers (an example is the rosary, an artifact found in fairly similar form in many cultures around the world). These affordances may explain why beads, when repurposed, are more likely to be used as an early counting technology: they are similar to but can extend the capabilities of other early technologies like fingers and tallies, and their repurposing may occur when numerical concepts and language are minimal.

Prehistoric Perishable Materials

Knotted strings, if such artifacts were used by Upper Paleolithic or Middle Stone Age societies, would not likely preserve. Neither would tallies made of wood or leaves, tokens made of seeds or grain, or marks made on the ground or body; we might also have difficulty recognizing tokens in the form of manuports, like a collection of pebbles. All of these counting technologies are attested in the ethnographic literature, and their prevalence in early counting suggests that the archaeological record may significantly underrepresent the time depth for numerical cognition, which likely included fingers and perishable materials before incorporating nonperishable materials. This circumstance suggests that archaeologists approach the material record with a caveat in mind: in addition to the need for caution in construing quantificational intent, there is an equal and somewhat opposed requirement to recognize that by the time nonperishable materials are used in counting, people have generally been counting for some time.

Conclusion

Materiality is so much more than tools that merely serve and externalize our mental computations, even if it is currently underappreciated for its constitutive functionality in human cognition (Malafouris, 2013). The lack of appreciation, however, need not remain the case. The way forward includes questioning the assumptions that sequester mental activity to the brain (Renfrew & Malafouris, 2008; Tallis, 2011), expanding and improving our investigative techniques so they include the larger cognitive system (i.e., not just brains but bodies and materiality; not just after the fact but during their interactivity, etc.), and finding ways to reconcile the short time spans considered by psychology with the longer temporalities involved in material, cultural, and genetic change (Overmann 2016*a*, 2016*b*). Such an approach is necessarily interdisciplinary, which also means adopting theoretical frameworks capable of reconciling data from evidentiary sources whose foundational assumptions will often be in conflict with one another.

Once we adopt the perspective that materiality is constitutive of our cognition, we can "notice phenomena like artifactual accumulation and the emergence of addition, affordance similarities of body-counting and language, or the structural properties of Chinese numerical notations and mathematical task performance, and investigate the ways that materiality co-creates and influences our numerical thinking" (Overmann, 2015*b*, p. 9). That is, we will start to see how materiality shapes the human mind through its semiotic qualities and agency and become able to question why its role in this regard is generally so transparent. We can start to investigate how materiality interacts with language to yield abstract conceptual domains and get a better grasp of what abstract conceptual thought is as a phenomenon distributed over psychological, behavioral, and material components. If there is much to be done, and discomfort in the challenge of it, the end result may be that we are better able to understand the mysteries of our past and present human becoming.

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Notes

1. The perceptual experience of quantity is governed by attentional constraints on object individuation and the Weber-Fechner constant of just-noticeable differences; these functionally divide quantity appreciation into *subitization*, the ability to appreciate small quantities (up to 3 or 4) as individuals, and *magnitude appreciation*, the ability to appreciate larger quantities (above 3 or 4) as differentials (i.e., bigger and smaller) if their difference falls above the threshold of noticeability (Piazza, 2011).
2. Chrisomalis (2010) notes the tendency for cumulative numerical systems to precede ciphered ones.
3. Because phonographically represented numbers like "three" require a system of writing be in place, they develop after spoken lexical numbers (Chrisomalis, 2010), so they appear to the left of the spoken forms.
4. Bundling and debundling arguably require the ability to count if they are to be performed with reasonable convenience; an alternative would be the use of one-to-one correspondence for every bundling or debundling operation, which seems infeasible given its laboriousness.

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6

Art Without Symbolic Mind

Embodied Cognition and the Origins of Visual Artistic Behavior

MANUEL MARTÍN-LOECHES

Symbolic vs. Embodied Perspectives in Explaining the Human Mind

In pursuit of the origins of our mind, a traditional perspective posits the advent of the *symbolic mind* as the explanation for most of our more conspicuous mental peculiarities as a species, such as language, religion, or art (e.g., Coolidge & Wynn, 2009; Klein & Edgar, 2002; Tattersall, 2012; Zaidel, 2010). Overall, this view postulates that the symbolic mind is absent in all other species, including those preceding ours within the *Homo* genus (and possibly in early *Homo sapiens*) and that this is the main reason for our success as a species. Symbolic behavior can be traced back to Blombos Cave decorative engravings covering the period from 150 kya to about 70 kya BP (Henshilwood et al., 2011) or to decorated ostrich egg shells from ca. 60–80 kya found in Africa (Texier et al., 2013).

This perspective is not without its issues. In this regard, the presence of probable "symbolic behavior" in Neandertals prior to the presence of our species in Europe, such as personal ornaments (e.g., Finlayson et al., 2012) or intentional burials (Rendu et al., 2014), has been reported. The recent discoveries of a deliberate Neandertal cross-hatch engraved in Gorham's Cave, Gibraltar (Rodríguez-Vidal et al., 2014) and geometric engravings on a shell in Trinil, Java, by *Homo erectus* (Joordens et al., 2014) add to this list of intriguing findings. Nevertheless, this kind of discovery would not be really problematic to extreme positions within the symbolic perspective linking the emergence of the truly symbolic mind of *H. sapiens* to the appearance of *figurative* art-representing recognizable objects in the world occurring circa 50–40 kya BP in Europe. Prior samples would be linear decorations and ornaments; perhaps "utilitarian," but not genuine art (White, 2003). On the other hand, burials without personal objects or ornaments, even if intentional, would not be straightforward evidence of symbolism; this might be due to pragmatic reasons (as discussed in Rendu et al., 2014).

Whatever the case, the symbolic perspective is, in my opinion, highly unsatisfactory and incomplete in terms of explaining overall human behavior. The symbolic perspective is rooted in old traditions within the cognitive sciences, according to which knowledge in the human mind is made up of *symbols*; that is, arbitrary, abstract, and amodal representations devoid of any resemblance to real external objects and events in the world (e.g., Glenberg, de Vega, & Graesser, 2008). Within this frame, human (*H. sapiens*) thinking would be equivalent to symbolic thinking, or thinking with symbols. As shown in Figure 6.1A, human language might emerge and benefit from this arrangement, tapping directly into these symbols that would, in turn, derive from direct interactions of the organism with the external world (actions and perceptions). Although this understanding might seem appropriate to explain the emergence of some traits, such as human language, it is not, however, apparent how thinking with symbols might mechanistically explain some of the other most striking products of the *H. sapiens* mind. In my view, this particularly applies to artistic behavior. In other words, the symbolic frame seems to provide neither sufficient nor necessary explanation for the emergence of art. In this chapter, I will explore alternative possibilities to symbolism for the emergence and evolution of artistic behavior. Current perspectives and findings from cognitive neurosciences will be a benchmark in this endeavor.

In cognitive sciences, the symbolic perspective is progressively being replaced by current models of *embodied cognition*, according to which mental representations are directly embodied and grounded in *sensorimotor* experience (e.g., Barsalou, 2008; Carota, Moseley, & Pulvermüller, 2012). Noticeable progress

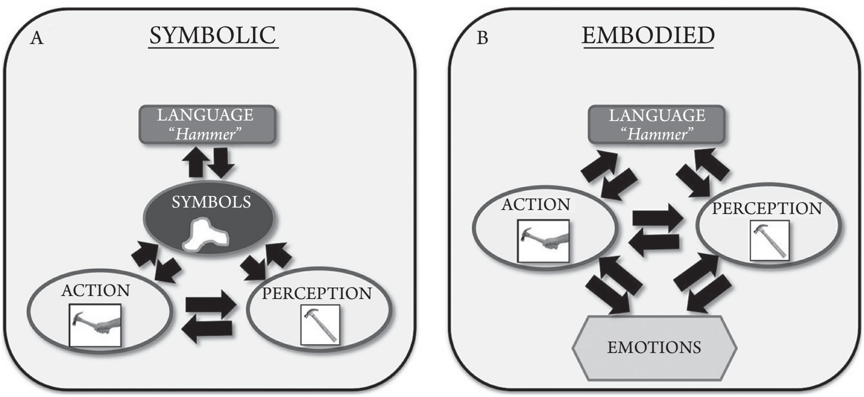

Figure 6.1 Symbolic (A) and embodied (B) conceptions of the human cognitive system.

within this perspective is demonstrated by including emotions as a relevant part of human cognition (e.g., Pessoa, 2008), an issue that has been largely obliterated in cognitive sciences, particularly in the symbolic frame, but is of great value to comprehend several of the most salient qualities of human behavior. Within the embodied perspective, to achieve full understanding of the act of speech, the linguistic system would straightforwardly access the perceptual and action systems of the brain (Pulvermüller, 2013), including the emotional reactions typically accompanying all perceptions and actions. Hence, no symbols are needed at all, at least according to most radical positions (Caligiore & Fischer, 2013; see also Figure 6.1B). From an embodied perspective, symbolism should be better replaced by *abstraction* and *integration*, two terms directly related to perceptual and action principles working in the brain according to traditional and current neuroscience views (Fuster, 2003, 2013; Luria, 1973). In this regard, the brain would be conceived as a *memory system* mainly devoted to perception and action, in which primary cortical areas would be most directly related to raw, neat representations of the external world, whereas surrounding association areas would exhibit progressively increasing levels of abstraction and integration in relation to both perception and action (Fuster, 2009).

As developed in this chapter, the origins of human art might be approached from the embodied perspective. Within this frame, the origins and evolution of human artistic behavior might be understood in more naturalistic, gradualist terms and independently of other human mental outcomes, such as language or religious thought. By focusing on the perceptual and action systems of the human brain together with the emotional features they convey, embodied cognition perspectives may complete, complement, or even replace symbolic accounts on the origins of art.

Because there is no clear consensus on how to define art, it appears convenient to point out a brief working definition of this intriguing behavior that will be used herein. I will consider *visual art* in a wide sense to include the marking of items (natural or artificial) with esthetic intentions or at least with other than merely (immediate) pragmatically functional purpose in itself (see Haselberger, 1961; Morriss-Kay, 2010).

Art as Source of Perceptual Pleasure for the Human Brain

The perceptual pole of the embodied cognition of art has been extensively developed (see examples in Chatterjee, 2014; Hodgson, 2006; Ramachandran, 2011; Zeki, 1999). Overall, one of the most recurrent ideas arising from neuroscientific approaches is that stimulation of the visual system is an important intrinsic source of pleasure for the human brain. Hereafter, a major reason for the existence and success of art within our species would be that art has the ability to outstandingly exploit this perceptual principle, often by virtue of *hyperstimulation* of the visual system.

Although some visual principles exploited by art in hyperstimulation of the visual system are relatively complex and abstract, such as the use of metaphors or high levels of abstraction (see e.g., Ramachandran, 2011; Zeki, 1999), most are rather basic and imply low levels of abstraction, such as symmetry, contrast extraction, perceptual grouping, or isolation of visual cues, to name just a few (Hodgson, 2006; Ramachandran, 2011).

Direct connections have been reported between associative visual cortex and parahippocampal cortex, in the limbic (emotional) system; both primary and association visual areas contain a large number of mu-opioid receptors, directly related to pleasure (Biederman & Vessel, 2006). Direct connections have also been described in the primate brain between visual areas, particularly association ones, and the amygdala, a core limbic structure with strong (negative and positive) emotional connotations (Costafreda, Brammer, David, & Fu, 2008; Pessoa, 2008). Hyperstimulation of the visual system is therefore prone to elicit strong emotional reactions, and this feature is exploited by art. Furthermore, contemplating a piece of art, particularly if it is considered aesthetically beautiful, also activates a number of brain nuclei and regions also implicated in more complex and abstract assessment of reward and emotional valence (e.g., Di Dio & Gallese, 2009; Kawabata & Zeki, 2004), such as the *anterior cingulate* (Cupchik, 2009), or the *orbitofrontal cortex* (OFC), normally activated whenever a beautiful object or event is in sight (Ishizu & Zeki, 2011). Another outstanding region in aesthetic appraisal is the *nucleus accumbens* (Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011), related to feelings of intense pleasure and actually the main target for most addictive drugs. Most of the regions activated when viewing art appear to be eventually related to general homeostatic processes, in line with suggestions that the brain treats art, and aesthetics in particular, like any other natural object essential for survival—like food or sex (Brown et al., 2011). There is general agreement that emotions elicited by art are rooted in the great utility of rewarding detection and recognition of relevant items in the surrounding space because the detected item might be food or a predator; that is, this mechanism has strong survival value.

That art is a source of pleasure by virtue of hyperstimulating the perceptual principles of the visual brain would certainly provide a natural explanation for the predilection in our species for this type of apparently nonsense (from a biological perspective) behavior without appealing to the symbolic mind as a requisite, at least for a vast number of artistic expressions. Indeed, under this perspective, dividing art into figurative versus nonfigurative would not be substantial because both would actually be exploiting most of the same perceptual principles. Consider, as an example among many others, that contemplating grotesque Renaissance figures can be enjoyed without knowing what they represent or even if they represent (or symbolize) anything.

It is admissible that the more abstract perceptual properties exploited by art may require a more modern human mind. However, this undoubtedly is not the case for many of the visual properties recurrently exploited by art. Although certain parts of the visual system seem evolutionarily new in our species, such as portions of the intraparietal sulcus (IPS), for 3D analysis of moving images (Orban et al., 2006), nonhuman primates largely share their visual systems with humans, with similar survival values. Even abstraction can confidently be achieved, at least to certain degrees, by most nonhuman primates, not to mention—by extrapolation—hominin species. The question is therefore how it is that only our species, *H. sapiens*, seems to exhibiting or being able to exhibit some kind of artistic behavior. Subsequently, I will summarize evidence from animal research apparently contradicting this assertion. It will be followed by a review of the archaeological record suggestive of artistic behavior prior to the emergence of *H. sapiens*.

Art out of *H. sapiens*

Chimpanzees and other great apes have been seen to produce lines and scribbles, usually unpredictable in terms of direction, location, or occurrence, with typical clustering and strokes (Davis, 1986; Iversen & Matsuzawa, 2008; Morris, 1962). Great apes also incorporate *negative space* (i.e., intentional blanks) into their production and can fill in simple figures (Zeller, 2007). Occasionally, circle- or triangle-like scribbles have been reported. Great apes do not seem to produce figurative art, and they might not be able to complete partial outlines (Saito, Hayashi, Takeshita, & Matsuzawa, 2010; but see its criticism in Watanabe, 2013, p. 154), although a scrawling figure close to the first representations of faces by human children has been reported (Morris, 1962).

Nonetheless, and importantly, chimpanzees are able to interpret photographs, realistic drawings, and even line drawings (Itakura, 1994; Tanaka, 2007). Premack (1975) observed that a chimp was able to "put together a face" from "primitive elements" provided by the experimenter (eyes, nose, and mouth of another chimpanzee cut out from a photograph). It is true, however, that interpreting line drawings, as is the case of some human traits like language, seems to require a critical learning period during youth (Tanaka, 2007). Crucially, all these activities do not need to be rewarded; they appear pleasant as such to great apes (Tanaka, 2007; Zeller, 2007). Overall, although more research is undoubtedly needed in this regard, several authors would argue for elements of artistic behavior in nonhuman animals (Watanabe, 2013), and it appears that at least great apes should not demonstrate serious difficulties in recognizing figurative art, at least to a certain degree.

On the other hand, there is much evidence apparently supporting that at least some essentials of artistic behavior may have been present in the human lineage far before the emergence of our species. A few selected examples will suffice to underline this point (Figure 6.2). One of the most cited findings in this regard is the Makapansgat pebble (Bednarik, 1998), a small jasperite stone (about 7 cm high) whose natural chipping and wear make it look like a rudimentary representation of a primate face. It was found some distance from any possible natural source in the context of *Australopithecus africanus* remains in the cave of Makapansgat, South Africa, and dated between 2.5 and 2.9 Ma ago. Although it has been definitely established as a nonmanufactured object, it has been proposed that because of its conspicuous color, shape, and markings reminiscent of a face, an australopithecine brought the pebble back to camp as a special, appealing object. Strong perceptual preference for faces has been reported for extant primates (e.g., macaque, chimpanzee; see Desimone, Albright, Gross, & Bruce, 1984; Parr, Hecht, Barks, Preuss, & Votaw, 2009) and humans (e.g., Hadjikhani, Kveraga, Naik, & Ahlfors, 2009), and so it could be plausibly assumed in australopithecines (see Figure 6.2).

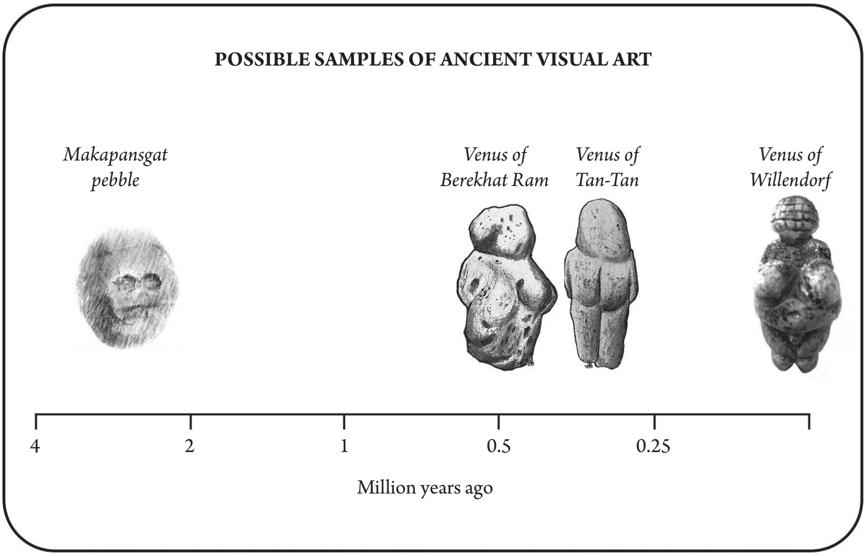

Figure 6.2 Some relevant milestones for the prehistory of art. The Makapansgat pebble is dated between 2.5 and 2.9 Ma BP. The Venuses of Berekhat Ram and Tan-tan have been dated between 300 and 500 kya BP. These items are possible examples of figurative art long before the advent of the mind of the *Homo sapiens*, represented here by the Venus of Willendorf.

Another example, attributed to *H. erectus* or *Homo heidelbergensis*, is the Venus of Berekhat Ram, a 3.5 cm-long red tufic pebble found at the Golan Heights (Goren-Inbar & Peltz, 1995). It has been created by natural geological processes giving it a general human-like shape; nevertheless, this shape was apparently deliberately accentuated by carving certain portions with stone wedges, suggesting that artistic intent is a serious possibility (d'Errico & Nowell, 2000). A possibly similar exemplar is the Venus of Tan-tan, a 6 cm-long piece of quartzite found in Morocco and dated between 300 and 500 kya BP (Bednarik, 2003). A number of findings in India belong to a comparatively similar evolutionary period. They include extraordinary rock engravings and cupules, like the cupule and meandering line in Auditorium Cave or the series of cupules in Daraki-Chattan Cave, both in Madhya Pradesh, dated between 200 and 500 kya BP (Bednarik, Kumar, Watchman, & Roberts, 2005). Recently, a shell has been reported in Trinil on Java with a zigzag engraving attributed to *H. erectus* and dated about 400 kya BP (Joordens et al., 2014).

Some objects like bird feathers, shells, bones or teeth with perforations, and, occasionally, remains of decoration, would also suggest the use of jewelry and personal ornaments by Neandertals and, therefore, an irrefutable aesthetic sense in this species (Finlayson et al., 2012; Zilhão et al., 2010). More recently, the aforementioned geometrical engravings from Gorham's Cave attributed to Neandertals (Rodríguez-Vidal et al., 2014) might add to products of *Homo* spp. other than *H. sapiens* in which artistic behavior seems admissible. Indeed, the Gorham's Cave cross-hatch, as well as the abovementioned zigzag engraving by *H. erectus* in Trinil, Java, would to some extent parallel Blombos Cave engravings by our species because these three would be hyperstimulating the most primary visual areas specialized in detecting lines with different orientations.

This type of evidence, as well as other existing examples, suggests some sort of capacity for artistic appraisal both before and not from our species. Samples of art not from our species are scarce, but this is probably the combined product of both their antiquity and consequent conservation constraints, as well as the availability of systematically explored sites (particularly in India and Africa). Interestingly, most of them have been largely controversial, and many authors still do not accept them. In my view, this is probably a consequence of some resistance within the symbolic perspective to admit figurative art prior to the emergence of a fully modern (symbolic) mind. However, as already discussed, figurative art would not necessarily represent a separate case; detecting a figure in the visual field would be basically exploiting similar basic visual principles as nonfigurative art. That "figurativeness" cannot be a cutting line in the evolution of art is also supported by the fact that many traditional communities in the past did not produce figurative representations (e.g., ancient Tasmanians; see Robson, 1983).

And yet we can see that the art produced by our species appears somewhat different from artistic expressions by other hominins. Art prior to our species, particularly figurative art, can be categorized as crude, basic, unrefined, notably less skilled. The Makapansgat pebble is a natural object; it was appreciated, but not crafted. Venus figurines dating back to 300 or 500 kya are also natural objects with some human intervention, but the latter is sparse. Most of the remaining pieces are limited to basic circles and lines. Differences are appreciable even in this nonfigurative art by considering the fine diminutive geometric patterns of Blombos Cave (perhaps with the only exception being the Trinil, Java, engravings by *H. erectus*). From an embodied perspective, if perceptual factors cannot fully explain these differences between species, it might be that it is art *production*, not its appraisal that was most limited before the advent of *H. sapiens*. This also applies to characteristics of artistic behavior in great apes, as described earlier.

The Action Pole: Biomechanics

Motor behavior is the consequence of accurate coordination of two main systems: musculoskeletal and neural. Current fine art, just like Paleolithic art performed 35 or 40 kya, requires a certain fine coordination of the muscles involved in the hand, wrist, forearm, arm, and shoulder—to say the least; overall, the entire body seems somehow involved—in an interdependent and complex interaction between proximal and distal joints (Dounskaia, 2010).

At the level of most of these musculoskeletal subsystems, there are manifest and significant differences between *H. sapiens* and extant nonhuman primates. Strong selection pressures affecting the upper limbs and (particularly) the hand during human evolution can be recorded and are probably mainly tied to technology.

Arguably, the biomechanics of the hand and upper limb of nonhuman primates makes art production difficult for them, particularly fine art. This might help us to understand their type of drawing production, as discussed earlier, as well as why they might at least partially understand figurative art but not produce it. One of the most known and conspicuous differences is the short thumb compared to the rest of the fingers in nonhuman primates, by virtue of which it is uncommon to come across full opposition between the thumb and all the fingers to the degree achievable in the human hand. This is due to the rotation possibilities of the human thumb and its relative length, as well as rotational movements of the other fingers, something that does not occur in any prehominid hand (Wilson, 1999). As described in Diogo, Richmond, and Wood (2012), Marzke and Marzke (2000), and Wilson (1999), nonhuman primates cannot perform, or are indeed limited in, a number of flexions and movements, such as "ulnar opposition" or the movement of the fourth and fifth metacarpals. Humans also have a much larger number of muscles going to the thumb, reflecting the important role of focal thumb movements in human evolution.

On the other hand, although some improvements can be accounted for in the hands of *Australopithecus, Paranthropus*/early *Homo*, and *Homo floresiensis*, like short fingers relative to thumb or changes in the ligaments suggesting capacity for prolonged periods of percussion, the majority of primitive features are still retained in these species (Marzke 1983; Marzke & Marzke, 2000; Wilson, 1999).

Importantly, there are also significant differences between the hands of Neandertals and *H. sapiens* even if they are the most comparable within our genus. Overall, the Neandertal hand was much stronger, with larger muscles and broader fingertips (Maki & Trinkaus, 2011; Niewoehner, Bergstrom, Eichele, Zuroff, & Clark, 2003). There were also differences in shape and orientation of capitate-metacarpal articulations and in relative lengths of distal and proximal phalanges, as well as in flexor mechanics over metacarpo- and interphalangeal joints (Marzke & Marzke, 2000; Niewoehner, 2001). As a consequence, Neandertals exhibited reduced flexion-extension capacities at the interphalangeal joints, as well as lower force capacities and force vectors at the distal phalanges, giving rise to less mechanical advantage for gripping at the fingertips (Trinkaus & Villemeur, 1991). This suggests that Neandertals would have had less precise control when manipulating small objects. Along the same line, it has been argued that the derived structure of the *H. sapiens* hand reflects functional adaptations related to more frequent precision grip usage, finer finger movements, and oblique grips, as required for engraving and incising (Niewoehner, 2001). An unpublished study (Culley, 2006) directly analyzed the specific biomechanics of art production, researching *H. sapiens* versus Neandertal differences in this respect. Most postures that appear unique to image-making among upper Paleolithic behavior (e.g., the precision-pressure pinch, the extension pinch) were found to be directly facilitated by features of the *H. sapiens* hand. To sum up Culley's (2006) conclusions, it appears that although Neandertals might have had some capacity for image production, it was demanding for them to draw or engrave meaningful, recognizable images, including linear, geometrical, or decorative patterns, and this plausibly precluded image production on a noticeable scale.

The contribution of biomechanics to the prominent differences in artistic behavior between *H. sapiens* and other human and nonhuman primates seems, accordingly, highly relevant. Nevertheless, this is probably not the whole story, as suggested by the fact that people with amputated arms are able to produce extraordinary artwork using their mouths or feet (Wilson, 1999). This would be highly similar to language, for which there are well-adapted organs reflecting specific evolutionary pressures for auditory speech production, but human linguistic communication can also be achieved by gestures, among other formats.

It is therefore possible that a core factor for fine art is to be found within the brain action systems.

The Action Pole: Neural Factors

Improvements in the visual systems of the brain with the most direct impact on motor systems have been proposed to have occurred within the human lineage (Hodgson, 2012; Wynn, 2002). One of these is the aforementioned enlargement of the intraparietal sulcus, which improved processing and manipulation of 3D objects. Another would have arisen in the *anterior supramarginal gyrus* (aSMG), permitting enhanced visuospatial ability linked to motor coordinates. Differences between humans and nonhuman primates in deliberate monitoring of one's own voluntary motor kinematics mediated by parietal cortex have also been reported (Kaneko & Tomonaya, 2014). These developments appeared to go one step further in *Homo neanderthalensis* and *H. sapiens*, where both frontal and parietal areas present further enlargements compared to other *Homo* spp. However, although these improvements may well add to factors helping to explain differences in art production between human and nonhuman primates, they might not do so for the differences between *H. sapiens* and Neandertals, since they would have been highly comparable in these features.

From my point of view, a good alternative candidate in explaining the main differences in motor skills between *H. sapiens* and other *Homo* spp. might be the *pyramidal motor system* and particularly its *corticospinal* division. The corticospinal is the chief motor system for controlling voluntary movements, requiring the greatest skill and flexibility for fine movements of the distal extremities, particularly of the fingers (Masri, 2011). It is also the last motor system to maturate (Martin, 2005). The neuronal bodies composing the corticospinal system (large pyramidal neurons, primarily in layer V of the neocortex) are located within Brodmann areas 4 and 6 in the frontal lobe (motor and premotor areas), as well as in areas 1, 2, 3, 5, and 7 in the parietal lobe (somatic sensory cortex; Martin, 2005). Indeed, the pyramidal system works as a single unit despite containing both motor neurons in the frontal lobes as well as sensory neurons in parietal areas. The latter receive continuous feedback from somatosensory receptors (in skin and muscles), information directly submitted to motor portions for a constant coordination and *unification* of motor and sensory aspects (Adams, Shipp, & Friston, 2012). Finally, the corticospinal system gives the ability to move each finger independently, a skill that reaches its highest degree in musicians such as pianists (Passingham, 2008).

Strikingly, it is only in humans and the most dexterous primates that the corticospinal system terminates directly on to the spinal motor neurons innervating the most distal muscles; humans (*H. sapiens*) present the overwhelmingly largest number of these direct terminations (Hofer & Frahm, 2009; Passingham, 2008). The cortical neurons where these tracts originate are much more excitable in humans than in nonhuman primates (Cavallo, Becchio, Sartori, Bucchioni, & Castiello, 2012). The thickness of cortical layer V in motor areas is also much greater in humans than in chimpanzees (Raghanti et al., 2008). Outstandingly, there has also been a considerable increase in the cortical surface of the corticospinal system given over to controlling hands and wrist movements in both the motor and sensory aspects in humans, to the extent that the cortices for the hand are three times larger in humans than in chimpanzees, whereas the hand of a chimpanzee is actually bigger (Passingham, 2008). The pyramidal system not only controls the hands, but also the feet as well as the lips, tongue, and speech vocalization (including the larynx). Interestingly, this might imply certain links between manual skills (including artistic abilities) and language, both also exhibiting a high degree of brain lateralization (Uomini & Meyer, 2013). Additionally, this could explain the possibility of good art produced using the mouth or feet, mentioned earlier, because the neural governor would be the same in either case (Ploog, 1992). Indeed, at least part of the extensive regions for the hands in the human sensory-motor cortex could be recruited, in their absence, to control other body areas.

Corticospinal system constraints might undeniably contribute to differences between human and nonhuman primates in artistic behavior. As a plausible scenario, some of these differences might yet remain between *H. sapiens* and other *Homo* spp., including the Neandertals. This would parsimoniously explain differences in skillfulness manifest in artistic behavior. This would also harmonize well with biomechanical data discussed earlier. Although direct evidence is still necessary, some data might indirectly support this assumption.

In this regard, when compared to other *Homo* spp., *H. sapiens* presents a specific brain shape represented in an extreme vertical development involving upper parietal regions in and around the *rolandic fissure* (Bruner, Manzi, & Arsuaga, 2003). This pattern seems to primarily relate to the somatosensory portion of the pyramidal system, and it cannot be disregarded that the primary motor as well as other portions of this system within the upper parietal lobes are affected as well. Strikingly, the hand representation in Brodmann's area 2 apparently overlaps with the pattern of human parietal expansion (see, e.g., figure 6 in Eickhoff, Grefkes, Fink, & Zilles, 2008). Brodmann's area 2 exhibits a potentially crucial involvement in human evolution (Padberg et al., 2007) and is implicated in both static and dynamic handgrips (King, Rauch, Stein, & Brooks, 2014). Accordingly, this morphological pattern might indicate some kind of reconfiguration of the pyramidal system comprising the corticospinal system, unique to our species, and presumably affecting hand use. However, assumptions in this regard must remain speculative.

Converging evidence might come from the archaeological record, from products biased by the corticospinal system other than fine art production. In this regard, *microliths,* small flakes and bladelets typically as small as 10 mm in length, could be recorded. Although microliths can be found as far back as 300–250 kya BP, this is indeed very occasional. The paradigm was actually established by *H. sapiens*, being very common in our species particularly starting 40 kya (McBrearty, 2012), although it had already been very prominent as early as 70 kya in Howiesons Poort, South Africa (e.g., Wurz & Lombard, 2007). Indeed, microlith production, in addition to their use in complex tools, seems very demanding for the corticospinal system due to their size and need for fine craft. This, together with biomechanical constraints in the musculoskeletal system that apparently limited the manipulation of small objects by Neandertals (as discussed earlier) could help to explain their lack of this type of technology more parsimoniously than would difficulties in understanding the complexity of fine tools, as has usually been claimed (e.g., Brown et al., 2012). Archaeological evidence supporting differences in manipulative behavior between *H. sapiens* and Neandertals also comes from the fact that the latter needed their teeth and mouth as a "third hand" to properly handle tools much more frequently than did our species (Bruner & Lozano, 2014).

More direct evidence might come in the near future from the genome. Although evidence is currently available for both *H. sapiens* (Schmutz et al., 2004) and Neandertals (Green et al., 2010), it is still far from straightforward. On one hand, available Neandertal genome sequences are far less accurate than the *H. sapiens* equivalent. On the other hand, although the *H. sapiens* genome is the most complete and accurate mammalian genome sequence currently available, it still contains many sequence gaps in complex genomic regions (O'Bleness, Searles, Varki, Gagneux, & Sikela, 2012). Furthermore, the roles and mechanisms of many genes are still largely unknown (ENCODE Project Consortium, 2012). Genetic differences have not yet been identified between Neandertals and *H. sapiens* unambiguously and specifically related to the neural arrangement of the corticospinal system. Liu et al. (2012) report that the MEF2-A regulatory gene in our species exhibits particular variants not present in Neandertals. The MEF2-A gene products affect the BDNF gene which, in turn, plays a critical role in developing the corticospinal system (Cárdenas-Morales, Grön, Sim, Stingl, & Kammer, 2014). HACNS1 is a gene regulating the development of arms and hands that harbors 13 human-specific mutations presumably related to opposable thumb and manual dexterity, probably in the frame of evolution of technology (Hünemeier et al., 2010). Actually, HACNS1 is one of the most representative human accelerated regions (HARs) of the genome (see Hubisz & Pollard, 2014). Furthermore, eight of the 13 human-specific HACNS1 mutations are also present in Neandertal but, unfortunately, the Neandertal genome does not provide information for the complete HACNS1 region (Hünemeier et al., 2010; Noonan, 2010), thus there are unknown possible differences in the remaining five loci. Finally, Neandertal versus *H. sapiens* differences have been reported in genes affecting musculoskeletal features specifically innervated by the corticospinal system, such as the CALD1 gene involved in actin- and myosin-binding protein that regulates smooth muscle contractions (Green et al., 2010). The field does seem promising, although the scope of the current conclusions is still rather limited.

Additional Reasons for Success: Emotions in Actions

To sum up so far (see Figure 6.3), there are both perceptual and motor aspects of artistic behavior that might significantly help us to understand not only the existence of this otherwise "bizarre" trait in our species, but also differences in this regard between *H. sapiens* and all other species. Because there are many commonalities between the perceptual abilities of human and nonhuman primates, the motor part of artistic behavior might be the major contributing factor to comprehend not only why nonhuman primates lack art, but also why fine art, comprising figurative art produced on purpose and prominently, only emerged in our species. I have focused here on significant differences exhibited by the corticospinal system, although differences involving other motor control

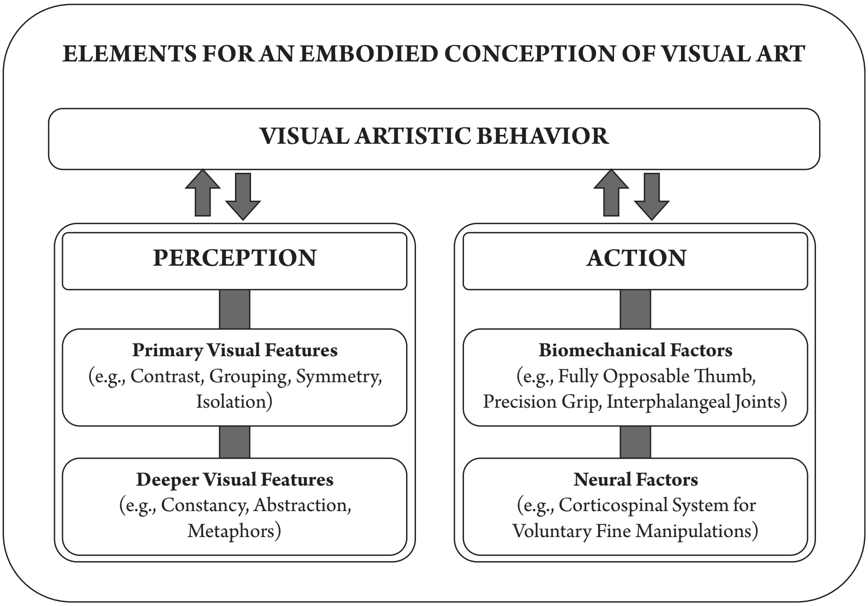

Figure 6.3 Blueprint of main factors significantly contributing to human artistic behavior according to the embodied cognition perspective.

systems in the brain are also admissible. The combination of biomechanical and neural constraints might have been critical in the emergence and evolution of art. At the least, it seems that they might have been a necessary prerequisite for art.

To complete this picture, emotional factors must again be called into play. On the one hand, emotions felt during art appraisal may be a critical reason for art's success, as explained earlier. On the other hand, motor constraints had to be raised to explain why other human (*Homo*) and nonhuman species do not exhibit artistic behavior, at least to the extent that *H. sapiens* do, despite largely sharing visual perception with us. However, to go one step further, the differences in the action pole of artistic behavior will also provide additional reasons for art's success in our species because performing motor actions is in itself highly pleasurable to our brain. Anecdotal but well-known daily life evidence for modern humans' motivation for fine motor acts governed by the corticospinal system can be found in the widespread appeal for doodling or scribbling when attention is occupied elsewhere. From a more academic setting, the relationships among motivational, rewarding, and primary cortical (corticospinal) motor systems through dopaminergic neurotransmitter circuitry are well-established (Keitz et al., 2003; Vitrac et al., 2014). In line with this, emotions have been seen to strongly modulate the excitability of the motor cortex (van Loon et al., 2010). Accordingly, producing art is pleasurable in itself, irrespective of and in addition to the pleasure produced by perceiving it (this also seemed to be the case for chimpanzees that enjoyed drawing, as outlined earlier). Furthermore, as subsequently developed, the emotional factors in art linked to action are not limited to emotions felt during art production.

It has been proposed (Freedberg & Gallese, 2007) that the artist's gestures when producing an artwork induce the empathetic engagement of the observer, activating simulation of the motor programs that correspond to gestures implied by the trace. The marks on the painting or sculpture are the visible traces of goal-directed movements; hence, they are capable of activating the corresponding relevant motor areas in the observer's brain. In this regard, Knoblich, Seigerschmidt, Flach, and Prinz (2002) have shown that observation of a static graphic sign evokes motor simulation of the gesture that is required to produce it. Activation of the motor cortex by contemplating handwriting such as scribbles or Chinese characters has been reported (Ticini, 2013). Furthermore, primary somatosensory and motor systems of the brain are activated during aesthetic and art appraisal (Cela-Conde et al., 2009) or during perception of artistic representations of tokens (e.g., bodies) in contrast to photographs of them (Lutz et al., 2013). Consistent with this, some authors have recently started to underscore the relevance of the primary motor and somatosensory aspects of art appraisal (Di Dio & Gallese, 2009; Freedberg & Gallese, 2007).

Thus, artist's actions could be appreciated as proper even when one simply contemplates an already finished artwork. This is actually in line with the postulates of the embodied cognition perspective, according to which understanding actions and situations necessarily implies their (internal) re-creation (Barsalou, 2008), not only when seeing those actions or situations directly in others, but also when being told a story, when reading, or simply during imagination.

That perceived movement, either your own or someone else's, is a source of pleasure is probably also applicable to other artistic formats like playing musical instruments or dancing (Morley, 2014). A corollary from the perspective developed here is that species that are not able to perform fine art due to motor-neural constraints could be deprived of this additional source of pleasure when looking at a piece of artwork. According to embodied cognition theories, if you have a different body you have different cognition; thus, art appraisal would not be exactly the same in other species, including *Homo* spp. other than *H. sapiens*, as it is in ours. In other words, other species could not enjoy art by *H. sapiens* in exactly the same way as we do.

Conclusion

By means of visual art, the paucity of applying current theories of embodied cognition has been brought out to approach the origin and evolution of some aspects of human behavior. It appears that focusing on both the perceptual and, particularly, the motor aspects (biomechanics and neural constraints) of artistic behavior, together with the emotional implications that these aspects convey, can improve our understanding of the main divergences between our and other species in this regard, as well as the emergence and evolution of this peculiar human trait. It has also been shown here that adopting current perspectives on embodied cognition in approaching human evolution may be a fruitful and fertile enterprise in the field of cognitive archaeology that might supplement or even conceivably replace symbolic explanations.

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7

Deciphering Patterns in the Archaeology of South Africa

The Neurovisual Resonance Theory

DEREK HODGSON

Introduction

It has been assumed that the accumulating archaeological finds from the Middle Stone Age (MSA) of southern Africa (SA), including the engraved geometric patterns from Blombos and Diepkloof, provide evidence of symbolic intent and therefore modern human behavior. These finds, some dating back 100,000 years, have led to a reassessment of the cognitive timeline of *Homo sapiens*, particularly with regard to their purported symbolic status that has been the focus of intense debate. The engraved patterns from these sites are not only similar but show a progression from simple to more complex motifs over tens of thousands of years, which begs the question as to why this was the case. A sociocultural explanation would predict greater variation in the patterns, both temporally and spatially, owing to the different cultural imperatives obtaining. A further issue that needs to be addressed concerns the preoccupation with geometric motifs at such an early date because iconic representation is obviously more meaningful. Moreover, the fine motor control required to produce these patterns suggests sufficient skill already existed to craft iconic figures. The aim of this chapter is to demonstrate that these issues can be potentially explained by a formal model based on how the early visual cortex processes information, which is referred to as the *neurovisual resonance theory*. This theory is based on the interrelationship between perception, the early visual cortex, the visuomotor system, implicit awareness, and embodied processes. Important developments in neuroscience since 2000 have provided verification of this theory, especially with regard to the relevance of Gestalt grouping and mirror neurons. In particular, it has been established that neurons in early visual cortex are tuned to and detect basic aspects of form, or perceptual primitives (e.g., edges [lines], intersections [angles], etc.) that conform to Gestalt principles of perceptual organization (Gilbert & Li 2012; Gilbert & Sigman, 2001; Kogo & Wagemans, 2013; Wannig, Stanisor, Pieter, & Roelfsema, 2011). Because the SA motifs conform to Gestalt principles, and given that recent neuroscientific research confirms that the early visual cortex deals with perceptual information using similar constraints, a useful alternative approach toward understanding the provenance of the SA "designs" is possible. A significant new addition to the neurovisual theory that links perception and action concerns the discovery of mirror neurons in humans (Keysers & Gazzola, 2006), which will be shown to have several important implications in the present context. This chapter will therefore describe the relevance of the neurovisual resonance theory to these issues by providing a detailed analysis of the dynamic interaction between perception, the early visual cortex, the visuomotor system via mirror neurons, and the earliest confirmed patterns from SA. Because this a "bottom-up" approach, it provides a more robust means of verifying the status of the engravings than do approaches relying on fully symbolic interpretations.

The first part of this chapter will describe in detail the various artifacts and patterns from SA and their relationship to accompanying incidental marks made prior to the intentionally made engravings. The second part will illustrate how the intentional patterns can be understood by examining the neural substrates of the visual brain, perception, and the mirror neuron system. Based on the observations from earlier sections, the discussion will assess the relevance of the SA evidence to the wider context of human behavior.

Archaeological Context

Early Patterns of the Middle Stone Age

The archaeology of SA has recently recovered a range of artifacts incised with geometric patterns dating from 100,000 to 55,000 years ago. These finds have led to a reassessment of when nonfunctional behavioral traits first appeared. Because such patterns were thought to be confined to the Upper Palaeolithic, their existence at a much earlier period has led to a reassessment of the timeline of "modern human behavior." Although similar marks as those from SA thought to be intentional have been found at sites in Europe and the Near East (d'Errico, 2003), most remain controversial. The SA artifacts have, therefore, given rise to considerable debate, with some arguing that they provide evidence of fully symbolic behavior (Henshilwood, 2007; Henshilwood, d'Errico, & Watts, 2009; Henshilwood & Dubreuil, 2009) whereas others advise caution (Botha, 2010; Malafouris, 2008a; Wynn & Coolidge 2007).

To determine the significance of the SA patterns, we need to assess the engravings from the perspective of embodied cognition and neuroscience in relation to how patterns are processed in the human brain. In this way, a formal model will be proposed that can potentially explain the preference for certain patterns during the MSA in SA. Understanding the nature and provenance of these patterns is all the more important given that they are accepted to be among the very first. This being the case, it is essential to determine what led to their creation.

Three questions arise from the foregoing:

1. Why do the MSA engravings from SA depict similar geometric patterns over an extended period rather than iconic representations?
2. Because there is an infinite range of possible patterns, why were certain patterns preferred for "artistic" expression?
3. Why do the patterns tend toward increasing complexity over time?

Sites, Dates, and Patterns

The engraved patterns from SA derive from widely distributed sites separated by several hundred kilometers that derive from Howiesons Poort or Still Bay contexts. The sites are located on or near the coast at the southern tip and southwestern area of SA with two located in Namibia at a considerable distance from the South African cluster (Figure 7.1). However, the corpus of engraved marks

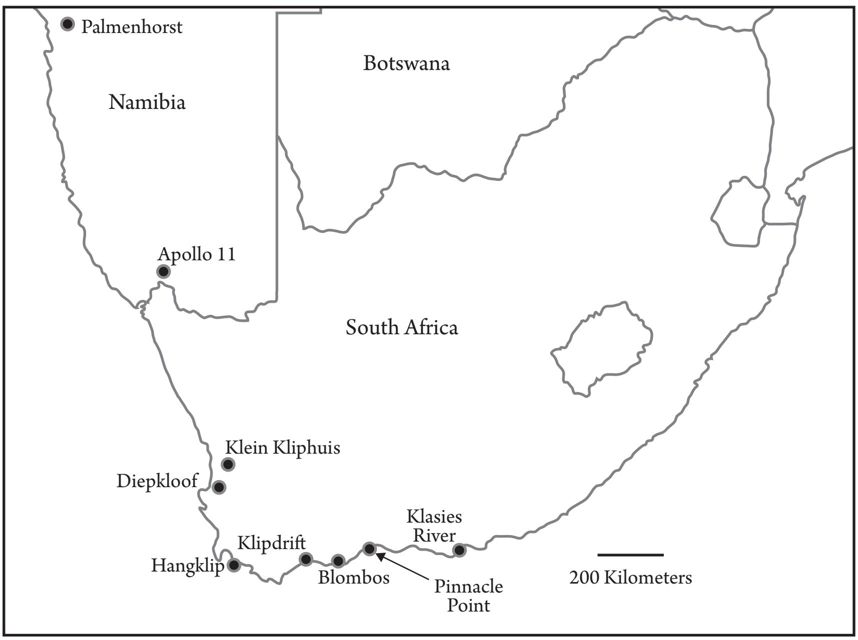

Figure 7.1 Location of sites where mark-making has been found (Blombos and Hangklip from Still Bay context; all other sites from Howiesons Poort layers).

recovered from these sites remains limited. The "designs" were made on a number of surfaces including ochre blocks, bones, pebbles, and ostrich eggshells, most of which were produced fairly rapidly in a single sitting with the same tool (Henshilwood et al., 2009). Blombos cave has produced a considerable number of patterns from an archaeological horizon spanning 100,000 BP–77,000 BP (Henshilwood et al., 2009). The eggshell engravings from Diepkloof derive from a longer period of 100,000 BP–55,000 BP (Texier et al., 2013). Finds from the other sites, Klasies, Klein Kliphius, Klipdrift Shelter (Henshilwood et al., 2014), and Namibia, also date to the MSA but, except for Klipdrift, have not been precisely dated. Also of interest is a hematized mudstone from Pinnacle Point Cave engraved with a single "chevron" dating approximately 100,000 BP (Watts, 2010). Because the Blombos and Diepkloof finds are sufficiently numerous to ascertain the temporal sequence, the degree to which the patterns underwent change has been tentatively assessed, which reveals an inclination toward slightly more complex patterns.

The patterns evince a surprising degree of similarity despite the extent of their spatial and temporal distribution and the different types of materials utilized. The long periods over which the patterns were created is particularly revealing: 23,000 years for Blombos 45,000 years for Diepkloof with, in both cases, the earlier motifs being simpler, which suggests a conservative rate of change that may be the result of drift, slow cultural evolution, factors related to perception and the visual brain, or a combination of all three. Other possible factors, such as doodling, have been excluded as an explanation because the engravings show a concern for fine motor control, an interest in detail, and focused concentration (Hodgson, 2006).

Although many of the patterns were carefully engraved, others are more ad hoc with the lines either broken or not completely straight or parallel, suggesting a first step in realizing such patterns. In effect, the motifs may be a record of the processes involved at the inception of mark-making and are, therefore, of great significance in ascertaining the factors giving rise to their initial production. The patterns mainly consist of repetitive lines in the form of angles, grids, crosses, and parallel lines, along with the odd dendritic and curvilinear shapes, most of which are no more than a few centimeters in length. Such motifs indicate a preference for repeated straight lines, intersections, and angles.

Overstepping the Mark

Close scrutiny of the incisions on ochre and other surfaces has allowed the intentional marks to be distinguished from accidental scoring. An unfortunate outcome of this procedure is that the accidental scratch/score marks tend to be viewed as unrelated to the intentional patterns. However, the incidental marks made to procure ochre show distinct similarities with the intentional patterns, which suggests the former may have been germane to the latter. As stated by Mackay and Welz (2008, p. 1529), "One possibility . . . is that scoring of ochre began as a means either of testing the suitability of the material to provide pigment or of increasing friction on a surface to be ground. Some scoring patterns may subsequently have become elaborate to the point at which design became an element of the process."

This parallels a claim Hodgson (2000, 2003, 2006) made regarding the way accidental marks produced in making and using tools served as a scaffold for the production of the intentional patterns. As Hodgson stated, "self-sufficient [intentional] marks could have derived from the accidentally produced scratches or cut marks created in the defleshing of bone or in the making and using of tools" (Hodgson, 2000).

And further: "A more likely explanation for the appearance of these motifs, however, is to be found in the fact that in the defleshing of bone and making of tools scratch marks of various persuasions will have been produced. Some of these will have accidentally assumed the configuration of a regular pattern and therefore became significant in the way described. This scenario is more probable because it is proactive rather than simply passive in that the implement used to produce scratch marks will have been conveniently at hand, so that a repetition of the initial procedure could easily have been enacted" (Hodgson, 2003, p. 117).

Unlike Mackay and Welz, Hodgson (2000, 2006) carried out an in-depth analysis of the relationship between the visual brain and intentional patterns and, importantly, predicted the kinds of patterns that would come to light even before the SA examples became available to public scrutiny.

At Klein Kliphuis, deeply scored repeated lines on ochre blocks made to procure ochre show an obvious resemblance to the intentional patterns. The resemblance of the unintentional marks with confirmed intentional engravings has also been noted by d'Errico, Moreno, and Rifkin (2012) for the Klasies River Cave engravings. Moreover, the intentional marks were made on the same ochre pieces as the accidental marks at both Klasies River and Blombos (d'Errico et al., 2012; Henshilwood, d'Errico, & Watts, 2009). Correspondingly, Henshilwood et al. (Henshilwood, d'Errico, & Watts, 2009) draw attention to an accidental radial scar on a block from Blombos (piece M3-9) created while preparing the surface and extended by adding an intentional incision to produce a dendritic motif. Similarly, the famous Blombos ochre block with the cross-like patterns is engraved over score marks, of which one of the latter is included in the design, and it is notable that the orientation of the first intentional lines follows the direction of the underlying score marks.

Thus, except for the Diepkloof eggshell patterns, most of the intentional engravings from the various sites of SA are depicted alongside existing natural scars/features or score marks made during surface preparation and are often included within the intentional designs. This suggests that the incidental marks played a fundamental role in the creation of the intentional patterns, a proposal that is further supported by the obvious similarity of the score/scratch marks to the intentional marks and mirrors the observation that this may not involve copying of conspecifics in that similar outcomes can arise "passively" due to the affordances implicit in the raw materials (Godfrey-Smith, 2014).

The role of incidental marks in making intentional patterns is consistent with the embodied/grounded cognition and the extended mind approaches to human endeavor that regards behavior as shaped by direct interaction with the environment through material engagement (Clark, 2008; Clark & Chambers, 1998; Malafouris, 2008a). In this regard, the incidental marks made for procuring ochre provided the initial stimulus from which the intentional patterns were formed. The question arises as to what factor(s) led to the incidental marks becoming valued and how this was translated into an intentional motor act.

Ostrich Eggshell Patterns from Diepkloof and Klipdrift Shelter

Up until now, we have not considered the Diepkloof Ostrich Eggshell Patterns, yet the similarity with the SA engravings is clear (Hodgson, 2014). The Diepkloof patterns (Texier et al., 2010, 2013) are just as ancient as the other SA patterns but are engraved on a different material; this, in itself, is revealing because one would expect the different surface properties to affect the kind of patterns produced. Further ostrich eggshell fragments with engraved patterns similar to those from Diepkloof have recently been recovered from Klipdrift Shelter (Henshilwood et al., 2014) located approximately 300 km to the west of the Diepkloof site. Interestingly, some of the Klipdrift patterns include cross motifs very similar to those from Blombos. These new finds originate from the Howiesons Poort techno-complex and are dated to 65.5–59.4 ka. Significantly, two further Howiesons Poort eggshell fragments with similar engravings have been reported from Apollo Cave, Namibia (Vogelsang et al., 2010) but also include traces of red paint. In addition, Brian Stewart (2012) has recovered eggshells from Spitzkloof A in SA of a similar age that appear to have been deliberately colored. Although ostrich eggshells probably served as water containers, the fact that they were deliberately enhanced through the application of color and patterns suggests a concern for materials other than the purely practical. Because ostrich eggshells are naturally geometric in form and are pitted with small spot-like indentations, these features would have caused resonance in early visual cortex. Alpert (2013) has shown that spots are particularly widespread in palaeoart because they invoke interest by creating a sense of vitality through stimulating the perceptual system. Because ostrich eggshells are geometric in shape, white, and replete with small indentations, they served as attractive objects in themselves and were more likely to undergo enhancement through the addition of patterns or color. However, the fact that the eggshell patterns were created with great precision and engraved on a useful portable object suggests that the engravings were significant in a way that goes beyond that of the other SA engravings. Nonetheless, the patterns display evident similarities with the SA engravings, which imply they may derive from yet to be discovered similar ochre/stone blocks or bone artifacts from Diepkloof and Klipdrift.

Whether the Diepkloof patterns pertain to group signaling or were more relevant to the individual remains to be established. However, the obvious similarity of the eggshell designs with the ochre engravings suggests that they were significant to the individual rather than the group. This inference is bolstered by the fact that even though the patterns are displayed on a highly visible everyday object, they do not diverge in style to any great extent from the other SA engraving, as would be expected if group status was a factor. However, as proposed elsewhere (Hodgson, 2014), the Diepkloof eggshell engravings appear to go somewhat beyond the individually based iterative resonance of the Blombos motifs and, as a result, had greater *potential* to indicate group identity. Nevertheless, in the absence of evidence to the contrary, it is prudent to regard the Blombos and Diepkloof engravings as restricted to personal use associated with a proto-aesthetic sense. This is consistent with the idea that a "passive" cue inherent to an artifact can, through individual-to-individual communication, elicit group engagement as opposed to social affiliation in the richer sense (Godfrey-Smith, 2014).

The SA engravings and Diepkloof patterns indicate a gradual increase in the complexity of the designs, a tendency that was noted by the archaeologists responsible for the Blombos and Diepkloof sites. Rather than deriving from cultural or random effects, this tendency can be potentially explained by the fact that the accidentally produced scratches/score marks served to prime the intentional marks. However, as a result of the founder effect, subsequent motifs would have derived from the original intentional marks and so on. Further evidence for this will be presented later in relation to the way the visual cortex and visuomotor system function.

The Evidence for the Model

Excluding the Diepkloof eggshells, most of the engraved objects from SA contain unintentional marks over or alongside which the intentional marks were made. The unintentional marks consist of:

- Scratch or score marks made as a result of procuring ochre, which are either narrowly spaced and superficial or are deeply indented but more widely

spaced and inadvertently produce repetitive line patterns, usually of the same orientation.
- Pre-existing natural marks that suggest a repetitive sequence of lines.

The main hypothesis of the present investigation is that the accidental scratch/score marks and the pre-existing natural features served as a prime for the intentional patterns resulting from the bias exerted by V1/early visual cortex and mirror neurons. This is supported by evidence from the actual materials and neuroscience as follows:

Actual Materials

- Some of the accidental marks were deliberately exploited by adding intentional marks; for example, as already stated, a deliberate line was added to an accidental scar to create a dendritic motif (Henshilwood, d'Errico, & Watts, 2009).
- Some of the engravings follow the orientation of the accidental marks, with several of the latter embedded in the former (Henshilwood, d'Errico, & Watts, 2009). This can be seen in the famous ochre block of cross-like motifs (M1-6) from Blombos, where one of the engraved lines is both nested in and a prolongation of a score mark.
- Because most of the engravings were created rapidly, probably in one sitting using a single tool, this suggests that they were made by one individual.

Neuroscience

- The patterns conform to Gestalt laws of grouping that is reflected in the way the early visual cortex encodes visual information (e.g., good continuation, proximity, symmetry, pragnatz).
- The accidental marks served to prime the visual system by hyperstimulating early visual cortex thereby producing preattentive resonance through fluency.
- The unintentional marks will have caused an undefined sense of arousal that suggests order and deliberate intervention, possibly through the activation the amygdala, mirror neurons, and associated systems leading to the attempted copying of such marks.

The crucial factor here is that the existing accidental marks served as a scaffold for the intentional patterns, which again accords with embodied or grounded cognition. Thus, the rapport between pre-existing cognitive abilities and the materials concerned led to a new ways of relating to and embellishing artifacts. We now turn to reviewing in detail the evidence from neuroscience in support of this hypothesis.

The Visual Brain, Neuroscience, and Pattern Perception

V1 and Early Visual Cortex

Thanks to neuroscience, the function of the early visual cortex has become clearer. When considered together with evolutionary constraints that affect visual perception, this has allowed the formulation of new approaches to understanding the archaeological record. Because the engravings from SA rely on visual perception and visuomotor control, they become susceptible to an analysis by visual neuroscience.

In general, the human brain can be interpreted as a sophisticated pattern detector in that it strives to hold constant, or invariant, those features important to survival (Tarr, 2000). In other words, the visual system has become particularly sensitive to and is concerned with decoding certain types of visual information from the optical array. At the lower, input end of the processing hierarchy—along the "what" pathway of the visual cortex—areas V1 (primary visual cortex), V2, V4, and lateral occiptal complex (LOC) encode basic information such as line orientation, intersections (for detecting edges and corners), contours, and symmetry whereby the receptive fields of the neurons steadily increase from V1 onward (Figure 7.2). Although processing at this level is generally not

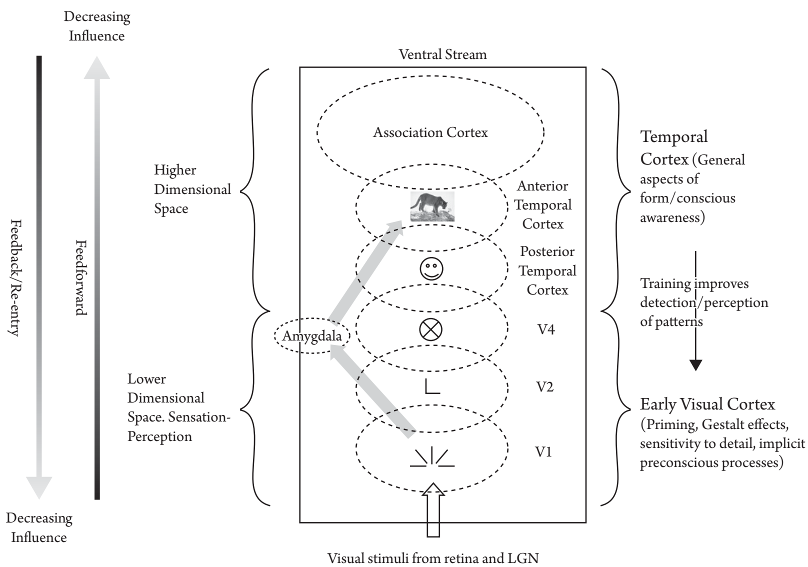

Figure 7.2 The processing hierarchy in the "what" ventral stream of the visual cortex showing the preference for simple lines and patterns in the early layers as well as feedback mechanisms from higher visual cortex and the place of mirror neurons in the system.

accessible to consciousness, it nevertheless affects perception, not least because the smaller receptive fields at such levels are specialized for perceiving detail. This is in contrast to higher levels that assemble information from the early areas into larger consciously experienced chunks. The higher and lower levels of this hierarchy act together dynamically according to requirements to the extent that feedforward, reentry, and cross-referencing occurs; for example, higher levels may require greater scrutiny of a stimulus and therefore recruit the lower visual areas through feedback (Lee, 2003). The early visual cortex thereby serves as a "basic" pattern detector for discriminating important visual information that assists conscious recognition in higher areas. Even the earliest layer, V1, deals with "raw" visual information in quite sophisticated ways by tagging important perceptual features (e.g., contours, angles, figure–ground) that undergo integration at this level through long- and short-range lateral neural links (Chen et al., 2014).

V1 and adjacent areas of early visual cortex are together consequently referred to as a "geometric computational engine" (Lee, 2003). This specialization arises from the fact the response output of neurons in V1 reflects the structure of natural scenes. Thus, the "organization of line segments in natural scenes parallels the geometry of interactions of primary visual cortex" (Gilbert & Sigman, 2001). The correspondence between visual neurons and the invariances of natural scenes is ethologically based and therefore consistent with the embodied approach to visual perception. In this respect, visual regularities of the natural world undergo accentuation by the early visual cortex in the sense that links between neurons that fire together are strengthened through Hebbian processes (Hebb, 1949), which, for example, facilitate contour alignment. Thus, the most salient contours consist of those that remain constant despite change in a way that is determined by neural integration. In effect, V1 serves as a high-resolution buffer with V1 and V2 together regarded as multifunctional bottom-up filters for "simple" feature extraction and segmentation relating to the preliminary disambiguation of visual stimuli (Chen et al., 2014).

V1 has also been implicated in mental imagery and feature binding, and it is tightly correlated with awareness in some situations through recurrent interactions with higher areas (Tong, 2003). As Chen et al. (2014, p. 691) state, "While the feedforward inputs endow the neuron with selectivity for simple stimulus attributes, the lateral and feedback connections can dynamically modify its response properties according to stimulus context and behavioral goal, and confer selectivity for more complex stimulus geometries." This occurs by selective weighting of local feedforward and long-range horizontal connection within V1 for encoding complex shapes (McManus, Li, & Gilbert, 2011).

Activity in V1 is also enhanced when a reward induces attention (Stanisor, van der Togta, Pennartzb, & Roelfsema, 2013). In nonhuman primates, this is achieved by providing concrete rewards, but in humans it occurs through self-reward, where patterns become valued in themselves (what Davis [1986] refers to as self-sufficient marks); because raised attention requires attending to detail, the acuity of V1 is thereby recruited.

Because processing in early visual cortex is preconscious, it acts implicitly on conscious awareness by extracting salient features important for detecting objects in scenes. These feature "primitives" facilitate the extraction of figure from ground, good continuation, common fate, symmetry, and the like, which conforms to Gestalt principles of organization as reflected in the way neural assemblies group sensory information as it ascends the visual hierarchy (Gilbert & Li, 2012; Gilbert & Sigman, 2001). Such preferences lead to visual biases such as the predisposition toward perpendicular and horizontal lines (the oblique effect), the corners of objects (corner enhancement effect; see Bertamini, Helmy, & Bates, 2013), and radiating lines (the radial effect; see Sasaki et al., 2006). An interest in depicting grid patterns may in fact arise from the corner effect in that grids consist of numerous connected angles leading to hyperstimulation of V1. Again, these preferences are implicit and preconscious and therefore affect perception surreptitiously. In fact, the "corner" effect may be responsible for the grid patterns that typify the SA engravings, which are especially prominent at Diepkloof. Remarkably, an engraved grid pattern dated to 39,000 BP made by Neandertals and similar to those from SA, has been found on the floor of Gorham's cave, Gibraltar, which confirms the archaic nature of such patterns (Rodríguez-Vidal et al., 2014). These patterns, it should be added, evince a striking similarity to nearby natural cracks on the rock floor of the cave. Interestingly, whenever a lack of control predominates—a frequent occurrence in the lifeways of SA groups—the propensity to see patterns in anomalous shapes tends to increase (Whitson & Galinsky, 2008).

Gestalt Principles and Early Visual Cortex

The importance of Gestalt principles of organization to understanding repetitive marks also needs to be factored in because recent neuroscientific evidence demonstrates that such principles operate at a preattentive level in V1 as well as at other levels of early visual cortex (Das & Gilbert, 1999; Figueiredo et al., 2005; Gilbert & Li, 2012; Gilbert & Sigman, 2001; Harrison & Tong, 2009; Murray, Kersten, Olshausen, Schrater, & Woods, 2002; Qiu & von der Heydt, 2005; Roelfsema, 2006; Sasaki et al., 2006; Shibata, Watanabe, Sasaki, & Kawato, 2011; Supèr, van der Togt, Spekreijse, & Lamme, 2003; Tong, 2003; Wagemans et al., 2012; Wannig, Stanisor, Pieter, & Roelfsema, 2011). These principles govern the way visual neurons coordinate visual information in terms of, for example, the aforementioned Hebbian principle of what fires together goes together, which is referred to as low-level or base grouping (Roelfsema, 2006) that depends on neurons tuned to feature conjunctions. Gestalt grouping of this kind can be found in the SA engraved patterns and given the significance of Gestalt principles to the functioning of V1, the reason for this becomes obvious. Interestingly, even the peripheral retina (i.e., nonfoveal) is able to pick up some aspects of stimuli that are suggestive of contour integration based on Gestalt principles, and these are then transmitted to V1 (Kuai & Yu, 2006).

The neurophysiology of the primary visual cortex also determines Gestalt principles through inhibitory and excitatory short- and long-range connections (Das & Gilbert, 1999). Because low-level processing in early visual cortex is based on Gestalt principles with regard to the coordinated firing of neurons (Chen et al., 2014), these factors affect behavior through priming in circumstances where visual perception and visuomotor activity are prominent.

Priming

Priming is especially important to understanding the origin of the marks from SA because it provides a critical factor that influences both perception and motivation to act. Numerous experiments have shown that priming biases preferences in ways unknown to the individual (Winkielman, Schwarz, Fazendeiro, & Reber, 2013). For example, images can be presented so rapidly that they remain inaccessible to conscious awareness, but when later asked to state image preference from a sequence of consciously perceived options, individuals tend to choose those associated with primed images. Priming can even occur when objects are presented once, thus confirming that the effect ensues with minimum input (Voss & Paller, 2010). Moreover, certain visual displays are more liable to visual priming because they are processed with alacrity by the early visual cortex due to their importance in detecting and identifying objects. Perceptual priming also refers to the ease with which low-level surface information of a stimulus is influenced by simple repetition, figure—ground contrast, duration, and the like, which is associated with perceptual fluency (i.e., the ease by which information flows through the visual system) that invokes a hedonic response (Winkielman et al., 2013). Thus, information with high fluency is regarded as positive because it signals that a stimulus has been encountered previously or appears familiar.

Priming and fluency may help explain why humans spontaneously prefer certain visual patterns, especially those with regularity, order, and symmetry (Bertamini, Makin, & Pecchinenda, 2013; Westphal-Fitch, Huber, Gómez, & Fitch, 2012). In fact, abstract, nonsemantic patterns are typical of stimuli that induce fluency and are elicited automatically, thus generating a proto-aesthetic response (Bertamini, Makin, & Rampone, 2013). Schacter, Wig, and Stevens (2007) found that posterior areas of the ventral visual stream are implicated in priming for physical stimuli (perceptual priming), whereas later areas are concerned with processing semantic features through conceptual priming. Perceptual priming therefore precedes semantic priming (Schendan & Lucia, 2010), which is pertinent for assessing whether the SA engravings are symbolic. Moreover, perceptual priming has been found to occur by way of repetition-induced fluency in the visual cortex (Vargas, Voss, & Paller, 2012).

Stimuli with high fluency, as elicited by simple repetitive patterns, accordingly arouse a positive emotional state, whereas those with low fluency, as elicited by random patterns, signal the opposite. This effect receives empirical support in that the ease of perceiving stimuli leads to increased preattentive activation of the zygomaticus major muscle (the "smiling muscle") even when individuals remain unaware of the fact (Winkielman & Cacioppo 2001). In addition, mu-opioid releasers, which induce pleasure, exist along the ventral visual stream, although in early visual areas these are more sparse than in higher association cortex (Biederman & Vessel, 2006); yet V1 and V2 remain active for longer and under different viewing conditions compared to higher areas and are recruited a second time through dynamic feedback when the higher areas find a stimuli interesting.

These observations suggest that simple repetitive patterns are preferred because they consist of pared down stimuli that easily mesh or resonate with the early visual cortex and elicit a positive but undifferentiated, hedonistic state (Bertamini, Makin, & Rampone, 2013; Rampone, Makin, & Bertamini, 2014; Winkielman et al., 2013). Consequently, because artificial visual patterns are created through feedback to the visual system, so particular patterns become adapted to the way human vision functions (Graham & Redies, 2010). Notably, V1 is especially recruited when geometric line drawings are scrutinized due to the fact that they cannot easily be categorized as objects and thus entail an analysis of the fine spatial features (Figueiredo et al., 2005). Interestingly, the tuning curves of neurons in early visual cortex become more finely honed, especially in V1, when individuals create or interact with simple patterns. In effect, when a pattern is observed the first time round, this fine tunes or primes neurons in early visual cortex so that they are subsequently able to discern the same stimuli the next time round with greater ease (Schoups, Vogels, Qian, & Orban, 2001). This mechanism may underlie the tendency toward producing slightly more complex patterns, which also accords with the interaction between perceptual fluency and familiarity in that becoming accustomed to simple lines leads to the production of incrementally more complex shapes known as the *inverted U-shape* effect (Hodgson, 2014; Reber, 2012). Thus, improvement in perceptual discrimination with self-induced training is thought to be associated with greater interplay of mutual information between V1 neuronal responses and the task stimulus (i.e., the materials engaged; Li, Piëch, & Gilbert, 2004).

Neural Synchrony

In support of the fluency effect, electroencephalogram (EEG) studies of the early visual cortex found that electrical oscillations become synchronized when a stimulus is stabilized, although some authorities claim that this is better explained through increased firing of neurons (Chen et al., 2014, but see Musall, von Pföstl, Rauch, Logothetis, & Whittingstall, 2014). Moreover, synchronization is enhanced in skilled individuals, such as artists, who proactively engage in producing patterns. Specifically, in a drawing task, synchrony in artists was found to be greater than in nonartists, which is consistent with greater neural economy in the former (Bhattacharya & Petsche, 2005; Kottlow, Praeg, Luethy, & Jancke, 2011).

Other studies using electrocorticographic recordings in nonhuman primates show that repeated presentation of a visual grating leads to a reduction in the firing rate of neurons in early visual cortex, but a steady increase of visually induced gamma-band activity (~40–90 Hz) in V1, as well as gamma-band synchronization between areas V1 and V4 and gamma-band activity in area V4 (Swettenham, Muthukumaraswamy, & Singh, 2009; Brunet et al., 2014). It is notable that the stimuli utilized in some of the studies producing gamma-band synchronization consist of gratings similar to those found in SA engravings. Decrease in neuronal firing rates is thought to be related to gamma-band synchronization because it is associated with pruning of the stimulus representation of pyramidal cells which, as a result, become sparser with increasing efficiency. Crucially, gamma band activity in the human brain has been linked to Gestalt perception (Kaiser, 2003). Because the engraved patterns of SA are based on repetitive visual and visuomotor acts, this suggests that synchronization and pruning, together with perceptual fluency and arousal, were important to derivation.

The Significance of the Mirror Neuron System

Although we have shown that early visual cortex creates arousal through positive affect that predisposes active engagement with the materials concerned, this does not describe how this leads to an intentional motor act. The mirror neuron system provides a means of addressing this question. Mirror neurons fire when a person views another individual performing an act (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Gallese, Keysers, & Rizzolatti, 2004). This relates to the concept of embodied simulation, whereby not only can the actions of others be mapped by activating one's own motor neurons, but also an observer's emotions can be simulated by reusing viscero-motor and somatosensory representations (de Vignemont & Singer, 2006; Gallese & Sinigaglia, 2011). Indeed, the mirror system is widely regarded as typically embodied in that behavioral outcomes tend to be implicit and automatic (Carr & Winkielman, 2014).

A recent empirical study investigated the relationship between geometric patterns and the mirror system and established that any apparent visible traces of hand gestures act as a cue to triggering an observer's sensory-motor representation of the same gesture (Sbriscia-Fioretti, Berchio, Freedberg, Gallese, &

Umilta, 2013). This study supports recent research that found simple abstract patterns activate the mirror neuron system in humans (Umilta, Berchio, Sestito, Freedberg, & Galles, 2012). This is based on a pre-reflexive, immediate understanding of the actions, emotions, and sensations of others which, in viewing geometric patterns, creates an empathic relationship between beholder and artwork (Freedberg & Gallese, 2007). In this context, sensory-motor and mirror neurons have been linked to arousal in the medial orbitofrontal and anterior cingulate cortices that are associated with both reward and an aesthetic response (Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011; Kringelbach, 2005). Because mirror neurons also fire when marks or patterns that imply human agency are observed (including accidental and natural features that imply human involvement), the automatic activation of mirror neurons while viewing such patterns will have provided the impetus to emulate such features. Furthermore, Sbriscia-Fioretti et al. (2013) propose that static geometric marks are suggestive of a previous gestural episode in that "the motor representation of the gesture implied in a perceived trace is part of the perceptual process even when the traces are devoid of symbolic significance." In addition, Bisio, Stucchi, Jacono, Fadiga, and Pozzo (2010) established that the decisive factor leading to biased automatically disposed behavior relates to whether the movement is perceived as biokinematic in that the motor responses are similarly influenced whether this involves observing dot-like stimuli or humans. These findings and the preceding related insights regarding the antecedence of perceptual priming over semantic priming (Schacter et al., 2007; Schendan & Lucia, 2010), again suggest that the SA engravings were not symbolic as proposed by Henshilwood, d'Errico, and collaborators (d'Errico, Henshilwood, & Nilssen, 2001; Henshilwood et al., 2009; Henshilwood & Dubreuil, 2009) because the visual contingencies described reveal that geometric stimuli preempt symbolic input (Voss, Schendan, & Paller 2010; Voss & Paller, 2010).

The foregoing suggests that the accidental score/scratch marks served to activate the mirror neuron system and associated sensorimotor areas that ultimately led to the making of the SA intentional engravings. This conjecture is supported by the observation that the fortuitous marks on the various SA artifacts were either natural, suggestive of human agency, or an accidental byproduct of functional activities. Because natural patterns and accidental score marks stand out or become salient thanks to their perceived order and regularity, they will have activated the visual cortex in the way described, as well as the mirror system. Correspondingly, Onians (2007) has noted that some Upper Palaeolithic cave art may have been instigated by the claw marks of bears (suggestive of agency), which stimulated the human mirror system and led to the production of several of the cave depictions that overlie the claw marks.

One other factor relevant to this issue is the general increase in sensitivity to shape in relation to pattern perception, which was necessary for making tools with different functions. We see an increasing variety of tool shapes in South Africa during the MSA and in Europe during the Upper Palaeolithic that goes hand in hand with the interest in "abstracted" proto-aesthetic geometric depictions. As hypothesized elsewhere (Hodgson, 2006), the generalization, abstraction, and transference of the skills needed to produce tools, particularly a raised sensitivity to shape, was co-opted to facilitate the depiction of simple geometric motifs. Thus, it is no coincidence that we find examples of geometric forms at Blombos and Upper Palaeolithic Europe just at the time when tool shape became more diverse.

The combined action of the early visual cortex, the mirror neuron system, and a raised sensitivity to shape for making diverse tools therefore accentuated the priming effect and engendered a proto-aesthetic interest toward the accidental marks mediated by a state of arousal reflected in the amygdala as well as the orbitofrontal and anterior cingulate cortices. Thus, the making of MSA engravings depended on a subtle interaction between accidental marks/natural features, the early visual system, mirror neurons, shape/pattern sensitivity, and associated cortical structures that facilitated arousal and empathy.

Discussion and Conclusion

The exploitation of coastal resources in South Africa with better climatic conditions will have allowed population rates to expand, thereby increasing the number of individuals engaged in procuring ochre or making and using tools (Marean, 2010), which also increases the possibility that the "significance" of the accidental/natural patterns were noticed. Because these activities require high acuity as well as precise hand–eye coordination, the automatic, implicit processes of the visual and mirror systems will have been particularly implicated. Thus, with more individuals in a community, both practical innovations and those with no obvious practical function were more likely to occur.

Due to the fact the SA engravings were found with a considerable number of shell beads (d'Errico, Vanhaeren, & Wadley, 2008; Vanhaeren, d'Errico, van Niekerk, Henshilwood, & Erasmus, 2013) thought to derive from necklaces, these also need to be considered. Because beads/necklaces were more likely to have acted as social signals, perhaps signifying group identity (but this is still contested), this suggests that different SA artifacts served different needs in that some were uniquely personal—relating to an individual engagement with the materials through proto-aesthetic resonance—whereas others were perhaps more socially mediated (Hodgson, 2014). Interestingly, Williams, Bornman, and Lombard (2015) found that the making of necklaces similar to those from South Africa involve pattern recognition that activates the higher order association cortex, especially parietal and frontal midline cortices relating to increased cognitive effort and control.

These insights suggest that caution is necessary when appealing to symbolic explanations to explain the relevance of SA engravings, especially because "symbolic" is often referred to by archaeologists in a generalized way as opposed to how the term is employed by semioticians who take account of the hierarchical levels of meaning involved (Sonesson, 2004). Some archaeologists, such as Pettitt (2011) and (2008b), have brought attention to this shortcoming by advising a more nuanced and considered analysis, insisting that the term should be precisely defined before an artifact is described as "symbolic."

Similarly, a number of commentators have drawn attention to the intertwining of cognitive traits with the materials engaged. That is to say, what is termed a higher dimensional but flexible cognitive space, dovetails with a lower dimensional, more inflexible modular sensory system (Edelman & Tononi, 2001; Serre, Oliva, & Poggio, 2007). Important components of the higher system consist of theory of mind, enhanced working memory, attention span, cognitive control, and consciousness. These criteria interact with various environmental contingencies, including the way material was exploited for functional purposes or otherwise. Some authorities, however, claim that invoking cognitive factors to explain the discontinuities of artifacts and expertise during the MSA is unnecessary because this can be sufficiently accounted for by changing population densities, climatic variation, and cultural criteria (Derex, Beugin, Godelle, Raymond, 2013; d'Errico & Banks, 2013; d'Errico & Stringer, 2011; Henrich, 2004). However, d'Errico and Stringer (2011) also state that the issue as to what led to changes in demography has yet to be ascertained. In response to this problem, Hodgson (2010) suggests that cognitive factors continue to be relevant, particularly when considered in conjunction with the mirror neuron system and theory of mind because these were crucial to enable the advantages of larger population rates and changing climatic conditions to be exploited and counteracted. Especially because research indicates that the mirror neuron system functions in a way that may allow practical skills to be easily acquired through imitation, so they undergo loss when a population becomes depleted through lack of skilled individuals from which to copy (Catmur, Walsh, & Heyes, 2007, 2009). This is due to the fact that the mirror system is believed to operate according to domain-general associative sensory-motor learning that is context sensitive and not a dedicated deterministic system with a specific evolutionary purpose (Cook, Bird, Press, & Heyes 2014, but see Gallese, Gernsbacher, Heyes, Hickok, & Iacoboni, 2011). This suggests that the opportunities for skills to be learned or endure are sensitive to ongoing population densities and/or climatic conditions, the latter of which often affect population levels. From this perspective, cognitive criteria remain relevant to understanding the origin of human behavior (Hodgson 2010, 2012*a*, 2012*b*) but only as part of a multivariate approach that includes issues pertaining to the environment, population, climate, and cultural considerations. Although this approach mirrors the eco-cultural niche modeling of d'Errico and Banks (2013), at the same time, it continues to regard neurocognition as an important factor in understanding the behavioral profile of early humans. Such a multivariate approach would therefore be part of a dynamic relationship involving various cognitive processes, as suggested by Barnard (2010), in which working memory (Wynn & Coolidge, 2007) would have been a vital ingredient.

The implications of the preceding insights is that a multivariate approach to understanding cognitive evolution needs to take account of intrasomatic (in-brain) as well as extrasomatic (external to the brain) events by factoring in the dynamic relationship coexisting between the various contingencies impacting on the two modes (as set out in Figure 7.3). Although the SA engravings served as an initial expression of extrasomatic expertise, they nevertheless remained "tethered" to the brain through neurovisual resonance compared to subsequent extrasomatic traces, the latter of which came within the purview of cultural evolution. Pettitt (2011) suggests that between 100,000 and 250,000 BP, pigment crayons were mainly concerned with individual decoration and enhancement but that the Blombos engravings were fully symbolic. The foregoing analysis, however, suggests that the SA engravings were mostly a self-sufficient response to the prevailing materials.

In sum, the relevance of intentional mark-making to sapient behavior may relate to the transcending of a passive appreciation of symmetry and pattern toward a more proactive exploitation of such components—at first, through a gradual, almost negligible, increase in varieties of shapes and forms—to a later

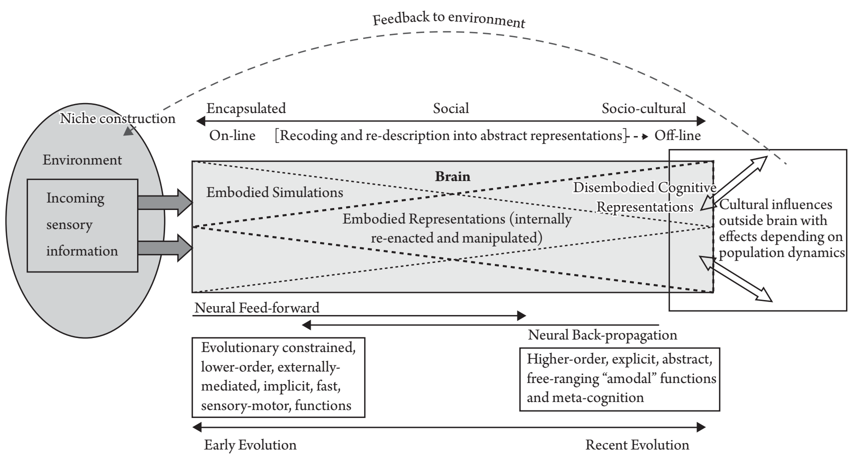

Figure 7.3 The multivariate graded interrelationship between various levels of cognitive processing. "Disembodied cognition" refers to the propensity to realize abstraction through meta-cognition. Note the feedback mechanism involving environment, brain, and ecological niche.

more exponential increase with the arrival of later humans (Hodgson, 2006). In this regard, material culture as a mean of communicating information needed to be discovered before it could be exapted for sociocultural signaling.

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8

Accessing Hominin Cognition

Language and Social Signaling in the Lower to Middle Palaeolithic

JAMES COLE

Introduction

From an archaeological perspective, discussions on the nature of hominin evolution in regards to the development of language and cognition must also include the methods of gauging that ability from the material culture of the Palaeolithic record. In this respect, I shall summarize here a theoretical perspective, the *identity model* (Cole, 2011, 2012, 2014*a*, 2014*b*, 2015*b*), which allows an assessment of the cognitive potential of ancient hominins through concepts of identity linked to visual display, material culture, and their role in hominin cognition, social communication, and language development. This chapter is intended to encourage discussion and invite debate across a number of disciplines rather than make categorical statements on hominin cognitive capacity, language development, social constructions, or behavioral characteristics. As such, the material culture focus (and related cognitive implications for the respective hominins) shall lie primarily with the Lower Palaeolithic, specifically the Acheulean, although there shall be discussions within the model that relate to the Middle and Upper Palaeolithic. The focus on the Lower Palaeolithic is to try and shed some still much needed light on when material culture started to play a conscious and direct role in mediating social relationships both within and between hominin social groups. For many, this relates to the imposition of form and standardization often associated with the Acheulean handaxe. This chapter shall present data that question this supposition using the British Palaeolithic record as a case study. More detailed analyses and results have been presented elsewhere (Cole, 2011, 2015*a*, 2015*b*); what shall be discussed here is a summary with particular focus on the impact for how archaeologists should view the cognitive capabilities of our hominin ancestors involved in material culture production.

Why has the handaxe formed such a focus of debate? The answer lies in the notion that the handaxe is seen to represent the first tools shaped through deliberate attention to shape and form (Iovita & McPherron, 2011; Wynn, 1979, 2004) corresponding to a significant shift in behavior and cognition from non-handaxe industries such as the Oldowan and Clactonian (McNabb, 2013; White, 2000; Wynn, 1981). Due to the poor preservation of organic artifacts from such deep antiquity, the main focus for Pleistocene hominin behavior must lie with stone tools, where tool production reflects varying degrees of planning, problem-solving, perceptual-motor coordination, and sociality (Stout & Chaminade, 2009). In particular, attention to handaxe form is perceived to be related to a behavioral standardization in artifact morphology associated with agreed cultural practice within hominin societies (Kohn & Mithen, 1999; McNabb, Binyon, & Hazelwood, 2004; Mellars, 1989, 1991; Monnier, 2006; Ronen, 1982; Saragusti et al., 1998; Stout & Chaminade, 2009; Wenban-Smith, 2004)—although see Chase (1991) for discussions against. The argument defending this position is as follows: the higher the degree of standardization and deliberate imposition of shape and form within handaxe morphology, the higher the influence social learning plays on the formation of lithic tools (McNabb et al., 2004; Monnier, 2006). Standardization in artifact morphology is therefore often seen to represent a desired end product in accordance with socially defined or accepted parameters which, in turn, are the consequence of mental categories that may be representative in nature (Monnier, 2006). The presence of symmetry within biface morphology is often seen to represent the epitome of standardization, present throughout Acheulean assemblages and increasing significantly in occurrence through the Acheulean as time progresses as a measure of increasing cognitive abilities within hominins (Hodgson, 2009, 2015; Saragusti et al., 1998). Therefore, one of the key research questions regarding handaxes is whether they were purely functional in design or whether they were imbued with significant cultural meaning expressed through the presence of symmetry and representing a clear attention to standardized form. As such, discussions of handaxe symmetry have implications that go far beyond the physical or cognitive demands reflected through *chaîne opératoire* or *façonnage*, but are crucial to our understanding/identification of when material culture began to play an active role in mediating hominin social relationships through an agreed cultural norm and the origins of linguistic behavior.

Part of this chapter therefore seeks to add to the cognitive handaxe debate by summarizing results of an analysis of bifaces encompassing some 1,838 artifacts (Cole, 2011, 2015*a*, 2015*b*) from the British Lower-Middle Palaeolithic record and presenting a behavioral framework that characterizes the material culture production and implications for social interactions through the cognitive lens of the identity model. In particular, this chapter will present evidence that will challenge a number of key assumptions held within the wider academic community in regards to the presence of symmetrical form within handaxe morphology. These assumptions may be summarized in the following statements:

- Acheulean handaxes are often symmetrical.
- Symmetrical handaxes are present in large quantities throughout Acheulean assemblages.
- The presence of symmetrical handaxes within Acheulean assemblages increases through time as a marker of increasing hominin cognitive ability.

Versions of these three statements appear time and again throughout the literature on bifaces; however, there are very little published data by which these statements are substantiated. The data summarized here against the behavioral framework should therefore engage and facilitate debate among researchers interested in hominin behavior and cognition.

Semiosis, Language, and Material Culture

The active use of material culture within social mediation must by necessity be linked to questions of language development (Davidson & Noble, 1989; Stout & Chaminade, 2012; Wynn, 1991). It is widely accepted that language lies in the domain of human communication, whereas animal communications, including vocalizations, remain entirely distinct (Barbieri, 2010; Deacon, 1997; Dunbar, 2004; Origgi & Sperber, 2000). The main reasons for this lie with the different capabilities for semiosis (activity based on signs) between animals and humans. There can be little doubt that animals have the capability for semiosis as they receive signals from the world, process those signals, and instigate an appropriate reaction (Barbieri, 2010; Kull, 2009). However, there is a noticeable difference in the ability for sign creation, reading, and interpretation between animals and humans that must be clarified before continuing. Peirce (1906) identified three types of signs in the world: an icon, an index, and a symbol. Deacon (1997), Wynn (1995), and Barbieri (2010) provide a useful synopsis of Peirce's original definitions in which icons are associated with a similarity between a sign and an object, indexes are associated with a physical or temporal connection between sign and object, and symbols are associated with a socially agreed conventional link between a sign and object.

The relevance of the three types of sign is in the degree of clarity it allows in defining the types of communication experienced by animals and humans. As explained by Deacon (1997), animal communications are based on icons and indexes, whereas human communications—in the form of language (both visual and verbal)—are based not only on icons and indexes, but also on the systematic and extensive use of arbitrary symbols (Barbieri, 2010; Origgi & Sperber, 2000). If it is accepted that language as a symbol remains distinct from the animal communications of icons and indexes and that language falls exclusively within the realm of the human condition (Whiten, 1993), then there must be a stage in the evolutionary development of the human species where hominins moved from communications centered around icons and indexes into communications incorporating symbols and the emergence of a language system. It is how to identify this important ability within the archaeological record—the move from communications governed by icons and indexes to communications governed by symbols (language) in the development of the human story—that forms the central component of this chapter.

Language, Cognition, and the Social Brain Hypothesis

In order for language to develop, the ability for symbolic thought must be incorporated into the hominin cognitive repertoire. The capability to conceive of the symbolic is intrinsically linked to the ability to perceive a notion of the abstract (Deacon, 1997). Identifying the presence of, and ability for, abstract thought in our hominin ancestors from the Palaeolithic record has been a long-standing question in Palaeolithic research (Barham, 2002; Carruthers & Chamberlain, 2000; Gamble, 2007; Lewis-Williams, 2002; Pettitt, 2010; Wynn, 1991, 1995). One hypothesis in particular has provided a useful heuristic for archaeologists to investigate and assess hominin cognitive potential in relation to the development of abstract thought and language: the *social brain hypothesis* (Aiello & Dunbar, 1993; Dunbar, 1996, 1998*a*, 2003, 2004, 2007; Dunbar, Gamble, & Gowlett, 2010). The social brain hypothesis is essentially a biological model relating to hominin brain encephalization where increasing group size and the subsequent complex social pressures required to maintain group cohesion selected for increasing brain size. Within hominin encephalization there is one area of the brain that has increased in size at a faster rate than any other brain component and that is the neocortex—a part of the brain of marked relevance to the social brain hypothesis because it governs reasoning and consciousness, stores memories, and organizes social relationships (Dunbar, 1998*a*). Therefore, the social brain hypothesis suggests that the larger the neocortex, the greater the ability of the animal to maintain social cohesion within larger groups.

A number of studies have recently corroborated the idea that, among primates, relative brain size and manifestations of social complexity such as group size are directly related (Byrne & Corp, 2004; Kudo & Dunbar, 2001; Lindenfors, 2005; Reader & Laland, 2002). The social brain hypothesis does not reject other models of brain evolution (e.g., Aiello & Wheeler, 1995; Faulk, 1990; Gibson, 1986; Henneberg, 1998), but rather incorporates the ideas that biology and physiology contributed to encephalization while social factors inspired the overall process. The social solutions to ecological problems (through increased group size) drove the intensification of social cohesion and subsequently provided the selection pressure for large brain evolution (Dunbar, 2003; Dunbar & Shultz, 2007*a*, 2007*b*).

The social brain hypothesis offers a further constructive heuristic in regards to assessing the cognitive ability of different hominin species by relating predicted group and brain size to orders of intentionality and a theory of mind. Crucial to the discussion on language and the aptitude for the abstract concept is that a theory of mind marks the beginning step in the development of abstract thought and symbolic construction. A theory of mind may be defined as the ability to comprehend the mental state of one's own mind and the mental state of the mind of the other (Baron-Cohen, 2001), and (I would explicitly state) to also recognize that the mental state of the other's mind may differ from the mental state of one's own. In regards to the development of language, it is important to note that in order to achieve an understanding of language (visual or verbal), a theory of mind is an essential component (Dunbar, 1998*b*; Origgi & Sperber, 2000).

In terms of hominin cognitive significance, a theory of mind may be related to a hierarchy of intentional states termed *orders of intentionality* (Dunbar, 2007; Premack & Woodruff, 1978). The concept of intentionality comes from notions of philosophy of mind and essentially relates to belief states epitomized through words such as intend, suppose, imagine, think, and know (Dunbar, 2007; Premack & Woodruff, 1978). Crucially, notions of intentionality describe self-reflective mental states or mental states experienced when we reflect on the contents of our minds (Dunbar, 2007). The importance of this in cognitive terms is that intentional mental states form a recursive hierarchy—Ben *intends* that Matthew *supposes* John to *imagine* Tim *thinks* that William *knows* (italics represent the orders of intentionality), and this hierarchical scale is commonly identified as levels or orders of intentionality (Premack & Woodruff, 1978). First-order intentionality represents one mental state (Ben *intends*), second-order represents two mental states (Matthew *supposes* John to *imagine*), and so on, with the preceding example representing fifth-order intentionality. The orders of intentionality and a theory of mind have been directly correlated, with a theory of mind requiring an individual to imagine the content of two minds: their own and that of someone else. Therefore, a theory of mind is equivalent to a second-order of intentionality (Dunbar, 2003)—Matthew *supposes* John to *imagine*.

Through such an ordinal scale, a great deal of cognitive and social complexity can be imparted even if only a small number of different mental states are linked together (Premack & Woodruff, 1978). Modern humans may operate at an upper limit of six orders (occasionally higher) of intentionality, although fifth-order intentionality is the average functional limit that we moderns tend to achieve (Dunbar, 2004, p. 47), and, as such, I shall examine the behavioral and material archaeological record accordingly.

There has been much debate about whether nonhuman primates and other animals have access to a theory of mind through mirror self-recognition experiments (Plotnik, de Waal, & Reiss, 2006; Povinelli et al., 1997; Reiss & Marino, 2001; Savannah, 2013) and the arguments stacked against such behavior genuinely representing such an ability (De Veer & Van Den Bos, 1999; Nielsen & Dissanayake, 2004). I have summarized these positions elsewhere (Cole, 2014*a*, 2015*b*), so shall not repeat them here. However, it would be worth reiterating that many of the theory of mind experiments tend to be conducted on trained, hand-reared, or captive primates with extensive human contact (Davidson & Noble, 1989), which may be inherently biasing the results of such experiments (see Tomasello & Call, 2008; van der Vaart & Hemelrijk, 2012, for useful summaries of these arguments). I would emphasize that in order to truly assess the cognitive capabilities of our closest living hominid cousins and other intelligent animals, wild populations should remain the focus of such research. A recent example of this comes from Crockford, Wittig, Mundry, and Zuberbühler (2012), where the authors have demonstrated through alarm call experiments that wild chimpanzees seem to recognize the knowledge and ignorance states of other members of their group. Although Crockford et al. (2012) do not directly relate such behavior to a theory of mind, there are certainly some very interesting and clear implications arising from the study that could do with some further investigation. Additionally, new methodological advances referred to in van der Vaart and Hemelrijk (2012) in assessing primate cognition through the use of computational modeling may well change the emphasis of the proceeding and following paragraphs in the future. However, based on current evidence available at the time of writing, it would appear that it is only humans who have an uncontested theory of mind, with the great apes only just able to achieve a second-order of intentionality—they do it, but not very well and not all the time, although this is highly controversial and probably a best-case scenario (Dunbar, 2007).

At present, in my opinion, it is only the hominin clade that has truly managed to break through the second-order intentionality boundary and attain a conscious theory of mind. Without a theory of mind, the ability for abstract thought and symbolic construction must remain elusive, and therefore a lack of a theory of mind must formulate part of the explanation for why animal communications are iconic and indexical rather than symbolic. Based on this reasoning, I view a theory of mind as a critical factor of the human condition, one essential to the cognitive separation of primate versus hominin evolution, whereas orders of intentionality are used as an ordinal scale of cognitive complexity in relation to the hominin archaeological record.

If it is accepted that a theory of mind or second-order of intentionality is an essential prerequisite for the development of language, then it stands to reason that the capacity for language must have arisen after the theory of mind/second-order of intentionality threshold was breached in antiquity. Dunbar has related the orders of intentionality to the brain sizes of primates and interpolated them into the hominin fossil record based on correlations among frontal lobe volumes, group size, and "achievable levels of intentionality" as a predictive exercise in estimating hominin cognition levels (Dunbar, 1992, 2004, 2007). Under Dunbar's scheme, it is only with the advent of *Homo* (and possibly the late *Paranthropines*) where a second-order of intentionality is predicted to have been achieved by our hominin ancestors. However, it is unlikely that a fully developed ability for grammatical language emerged in hominin cognition at the same time as a theory of mind was realized. Indeed, recent work (Shultz, Nelson, & Dunbar, 2012) seems to suggest that grammatical language may have developed close to 100 kya. I have proposed previously that a developed ability for language based on symbolic interaction not only requires a second-order of intentionality but may only be truly attainable with third-order intentionality as a minimum (Cole, 2012, 2014*a*, 2014*b*, 2015*b*). Furthermore, it is only with a fifth-order of intentionality that a full comprehension of the symbolic abstract occurs and subsequently grammatical language or speech develops as a selective advantage to allow the expression of the said symbolic abstract (Cole, 2011, 2012, 2014*a*)—defined here as a conceptual or metaphysical ideology made significant only through social and cultural constructions (Deacon, 1997). Such a complex notion can only be explained to an external individual or group in such a way as to facilitate equal understanding through grammatical language. Nonverbal visual display utilizing the body or material culture is simply not expressive or plastic enough to convey the full meaning of a totally abstract notion such as, for example, the supernatural.

Although there are many criticisms of the social brain hypothesis (e.g., Barrett, Henzi, & Rendall, 2007; de Ruiter, Weston, & Lyon, 2011), this chapter shall focus on one particular aspect: can the social brain hypothesis's cognitive predictions be tested against the archaeological or behavioral record (Cole, 2014*a*, 2015*b*)? Dunbar (2007) argues that there is no real need for the social brain hypothesis to be corroborated against the archaeological record because there is only limited insight available from the archaeological record (Shultz et al., 2012), and the social brain hypothesis explicitly deals with the mental processes that underlie social behavior rather than on the overt behavior itself or aspects of cognition that focus on instrumental skills like tool making. The tools in effect become a "red herring" because the mindsets that lie at the core of the social brain hypothesis are unlikely to leave a visible trace in the fossil record that archaeologists may relate to the tools themselves (Dunbar, 2007). However, there have been extensive archaeological studies identifying material culture as an active participant in maintaining and structuring social relations (Barham, 2010; Gamble, 1999, 2007; Gosden & Marshall, 1999; Ingold, 2007), supported through ethnographic studies illustrating that tools lie at the heart of mediating social relations, beliefs, and social practices (Killick, 2004). Even if it is often unclear which hominin species definitively produced different tool types, the act of tool making and material culture creation is intrinsically a social act when related to problem-solving and learning no matter how this was achieved (e.g., through imitation, observation, or demonstration; Bamforth & Finlay, 2008; Barham, 2010; Stout, 2002). Additionally, in regards to primates, there are some interesting studies that underline the importance of social environments in the retention of learnt skills and innovation in tool-making (van Schaik & Pradham, 2003). Therefore, if tool-making is correctly placed within the socialscape of their creation, and Palaeolithic tools are examined with this in mind, there can be little doubt that tools have great potential to inform on the behavioral and achieved cognitive complexities of their hominin creators (Cole, 2014*a*, 2015*a*, 2015*b*). In this chapter, I will summarize my attempt to use orders of intentionality as a heuristic in relating degrees of hominin cognition to the archaeological record through constructs of identity.

Why Identity?

First, it must be explained why concepts of identity may be useful when seeking to engage with the cognitive capabilities of extinct hominins. Questions relating to identity and the self have been repeatedly asked within many disciplines of academia, primarily because the ability for self-awareness and self-reflection is a quality unique to the human condition (Devos & Banaji, 2003). Specifically within the plethora of academic discourse on identity construction, psychology has a long tradition of grounding issues of the self and identity as being experienced in relation to the individual or group "other" (Andersen & Chen, 2002; Banaji & Prentice, 1994; Breckler & Greenwald, 1986; Brewer & Gardner, 1996; Chen, Boucher, & Tapias, 2006; Devos & Banaji, 2003; Greenwald & Breckler, 1985; Sedikides & Brewer, 2000). Psychological forays into the questions of identity are numerous and varied (see Banaji & Prentice, 1994; Chen et al., 2006; Devos & Banaji, 2003; Stryker & Burke, 2000 for basic reviews and bibliographies); however, there does seem to be a broad consent that individuals define themselves in comparison to their relationships with individual "others" and larger collectives "deriving much of their self-evaluation from such social identities" (Breckler & Greenwald, 1986; Greenwald & Breckler, 1985). The view of identity from this psychological perspective essentially dictates that the self is created and defined from the actions and reactions of the "other" in relation to the self (Brewer & Gardner, 1996). According to Brewer and Gardner (1996), people seek to achieve their identity in three ways:

- in terms of their own individuality
- dualistic relationships
- group membership

The assumption is that the three identities of the self co-exist within the same individual (Sedikides & Brewer, 2000). As such, psychology recognizes the formation of three types of self; the individual or personal self, the relational self, and the collective self (Brewer & Gardner, 1996; Sedikides & Brewer, 2000). The individual self depends on comparing the self to an "other" on an individual basis with the impetus of buoying up or ensuring the self's differentiation in psychology to the surrounding "other" (Brewer & Gardner, 1996; Markus, 1977; Sedikides, 1993; Sedikides & Brewer, 2000). The relational self is established based on the connections of personal attachment to significant others with the purpose of enhancing the significant other and preserving the relationship (Brewer & Gardner, 1996; Sedikides & Brewer, 2000). The collective self focuses on the formal relationships with others that have a common association to a group. The collective self's incentive is the enhancement of the so called in-group (the group that the self belongs to) versus the out-group (any other group or collection of individuals that are external to the in-group; see Brewer & Gardner, 1996; Sedikides & Brewer, 2000).

From these three classes of the self found within psychology studies, it is clear that issues of the self and identity are not singular nor static concepts but fluid notions that shift and change according to the social interactions of the individual in relation to the single or mass "other." However, as an active agent in their environment, the individual always has a choice to either accept or reject the identity that the "other" prescribes to him or her. The individual self also has the power to change and adapt the peripheral identities that the "other" may assign to fit his or her own perception of their own identity. This line of thought can be related to the idea of "symbolic interactionism" (Cooley, 1902; Mead, 1934; Schlenker, 1985*c*; Thomas, 1923) where "people are not just passive reactors to situations, programmed by society with fixed action patterns" (Schlenker, 1985*b*, p. 17). Indeed, as Schlenker (1985*a*, p. 65) goes on to state, individual people:

> project images of self and define and appraise one another to allow them to select goals and develop plans for their joint activities. Once identities are fixed in terms that are understandable and potentially agreeable to the parties involved, all other dealings can follow. Without these personal and social specifications, done consciously or unconsciously,

> confusion and tentativeness result because the nature and meaning of the person would be unclear.

Therefore, the individual must be a dynamic agent in the construction of the social world and in the construction of their identities within that world and should not be forgotten when discussing the composition of identity and self. The relevance for discussions of identity and the self in relation to the development of language lies in the mental acuity required to be able to conceive of an identity or a sense of self. A conscious self becomes the vehicle to identity formulation which in turn forms the mental bridge between first- and second-orders of intentionality. I *know* who I am because I have a realized sense of my self. Once a realized sense of self has been attained, the next step is to consider how the self interacts with and is perceived by the external world. In order to do this, the mental state of the other must be accessed, which in turn must instigate the journey to a theory of mind. The identity model (Cole, 2011, 2012, 2014*a*, 2014*b*) describes a theoretical perspective on how individual and group identity construction relates to a scale of cognitive complexity and the notions of the self and other.

The Identity Model

From an archaeological perspective, discourse on the nature of hominin evolution in regards to the development of material culture as a conscious mechanism of communication must also be related to discussions on hominin cognitive ability and methods of gauging that ability from the behavioral record (Stout, 2002; Stout & Chaminade, 2009; Wynn, 1979, 1981, 1985). The identity model proposes a theoretical framework that allows an assessment of the cognitive ability of ancient hominins through concepts of identity linked to visual display, material culture, and its role in hominin social communication. In contrast to the more traditional filter of brain size, the identity model represents a theoretical perspective allowing archaeologists to correlate the Palaeolithic record to the cognitive potential of hominin species based on notions of the self and others, linked into mechanisms of identity construction and perpetuation. The model sets out a minimum of seven categories of identity; each builds on, is informed by, and informs upon, the previous (Cole, 2012, 2014*a*, 2014*b*). Crucial for this discussion, each category of identity requires a certain minimum level of cognitive complexity on the part of the hominin. This minimum cognitive potential is measured through the orders of intentionality. Table 8.1 illustrates the essential basic definitions of the identity model and how they relate to the orders of intentionality.

Table 8.1 **A summary of the identity model (Cole, 2012, 2014*a*, 2014*b*, 2015*b*) and the relationship to orders of intentionality**

	Orders of Intentionality				
	1st–2nd order	***2nd order***	***3rd–4th order***		***5th order***
Categories of Identity	**Internal Identity:** Self is conscious of an awareness of own self. The awareness of own self forming the bridge between 1st- and 2nd-order intentionality	**External Identity:** Self is conscious of his own mind and that Other has a mind of his own. Subsequently, Self is also aware that Other may hold an opinion of Self other than that encapsulated within Self's internal identity	***Intex Identity*:** Is the identity that Self desires Other(s) to buy into. ***Perpetuated Intex:** Using material culture/ behavior to broadcast the intex.	**Collective Identity:** Self's belief in a commonality of understanding of the whole group.	**Abstract Identity:** An ideational component to Collective Identity. **Perpetuated Abstract:** Using material culture/behavior to broadcast the Abstract Identity.
Fictitious Intentionality Example	**Donald (the re-enactor) *believes* he is a Viking.** This is a 1st- to 2nd-order of intentionality because Donald is aware of his own identity (a Viking), rather than Donald just being aware.	**Donald *hopes* that David (a fellow re-enactor) *believes* that Donald is a Viking.** Donald wishes to join David as a re-enactor.	**Donald *desires* that David *believe* that Donald *thinks* he is *an exceptional Viking warrior*** *Donald dons the armour and weapons of a Viking and presents himself to David. Donald uses material culture (perpetuated intex) to project a specific desired identity of himself (intex) as a Viking.	**Donald *knows* that the re-enactment group are *aware* that David *believes* that Donald *thinks* he is a Viking.** Donald joins David in a mock battle lineup with David's re-enactment group.	**Donald *intends* David to *think* that the Viking deity Thor *desires* the group to *accept* Donald's *belief* in his own intex (that he is a Viking).** Donald achieves this by telling David (using speech) that the necklace he is wearing is a sign of Thor's favor and that Thor has given Donald extraordinary prowess as a Viking warrior in the upcoming battle.

(*continued*)

Table 8.1 **Continued**

	Orders of Intentionality			
	1st–2nd order	***2nd order***	***3rd–4th order***	***5th order***
	Potential behavioral and archaeological predictions for perpetuated intex/abstract		• Social communication is centered around visual display, gesture, and limited vocalizations. The body and material culture begin to play a more pronounced role in extending the body's boundary and identity perpetuation, broadcast on a context-independent basis. • If assemblages have a definite bias toward "true" symmetry or contain artifacts of "extraordinary design" (e.g., giant handaxes), then it may be that such artifacts have an implication beyond the purely functional and may hold some social signaling significance. Ochre use for visual display purposes (such as body adornment) may be placed here.	• Social communication is centered around visual display, gesture, *and* grammatical language. The body's boundaries are now fully extended through material culture on an individual and group basis with material culture adopting a deliberate functional *and* symbolic role in identity perpetuation. • Material culture with a purely nonutilitarian design enters the archaeological record in the form of ornamentation (e.g., beads), art, and figurines.

From Table 8.1 it can be seen that the key points of interest, archaeologically speaking, are the *perpetuated intex* (intex being an abbreviation derived from "internal to external") and *perpetuated abstract*. Perpetuated intex deals with the deliberate manipulation of how the other views the external identity of the self in relation to the self's intex identity, or, in other words, the way an individual desires to be seen by others. In this respect, there is some degree of similarity with the Wiessner (1983, p. 258) notion of assertive style defined as a formal variation in material culture that is personally based and that carries information supporting individual identity. Perpetuated intex at the third- to fourth-order intentionality bracket involves symbolic broadcasting on an individual-to-individual basis and on a larger individual-to-group basis. The use of the body and material culture within this third- to fourth-order intentionality context relates to physical body manipulations such as gesture or visual displays, in which material culture is symbolically involved in structuring social interactions, tacking between individuals and the group (Gamble, 1998). The body and material culture become the context and the engine for the effective broadcast of perpetuated intex. In order for the manipulation of the perpetuated intex to carry meaning across to the other from the self, the self must be sure that the other will correctly interpret the intended meaning. In this instance, culture—as a function of collective identity—would be the framework that ensures standardized meaning, agreed social convention, and commonality of understanding is present.

Abstract identity and perpetuated abstract deal with the deliberate creation and dissemination of an ideology. In many respects, there is a clear affinity to the idea of emblemic style as described by Wiessner (1983, p. 257) in which there is a prescribed adaptation in material culture with a distinct referent transmitting a clear message to a defined target population about conscious affiliation or identity (e.g., a flag). I would suggest that a fifth-order intentionality is the minimum cognitive requirement to not only conceive of an abstract notion such as an ideology or emblemic style, but to successfully communicate the abstract and arbitrary nature of such an identity to the other individual(s) through perpetuated abstract. Perpetuated abstract then becomes the mechanism through which the abstract identity is broadcast and should be closely linked to the appearance of grammatical language because that is the only form of communication flexible enough to get the intangible arbitrary notions of abstract identity across to the other individual(s) without misinterpretation or confusion. Visual display alone, in this instance, is simply not plastic enough to fulfill this role without some sort of additional explanation. Archaeological evidence for a perpetuated abstract could be linked to indicators for grammatical language such as art, figurines, or ornamentation (e.g., Aubert et al., 2014; Conard, 2003; d'Errico, Henshilwood, Vanhaeren, & van Niekerk, 2005), where it is the physical expression of arbitrary abstract notions through speech, art, ornamentation, and figurines that constitute the perpetuated abstract.

The crucial point to take away here is that once grammatical language markers enter the archaeological record, fifth-order intentionality must have been reached by the hominin creating the marker, although, at the time of writing, such signatures are only related incontrovertibly to anatomically modern humans. This chapter aims to identify the appearance of perpetuated intex within the archaeological record and subsequently recognize when artifacts were first consciously incorporated into systems of social communication and visual display within a culturally meaningful context.

Sites and Methodology

The eight sites and assemblages summarily presented here focus on the British Lower to Middle Palaeolithic (see Cole, 2011; 2015*a* for more detail; Cole, 2015*b*). Such a regional study was thought to be a useful comparative analysis because Britain represents the very edge of the hominin world for *H. heidelbergensis* and *Homo neanderthalensis*—the typical hominin species associated with the sites mentioned. Being on the edge of the hominin world, it is thought that if there was a genuine species-level of cognition and behavioral practice—such as regularly making symmetrical handaxes as markers for social signaling—then such an important social practice or behavior should manifest itself as the hominins explore the landscape at the very limits of their geography. The sites and assemblages examined within this study span a range of dates from Marine Isotope Stage (MIS) 13 to 3, allowing the investigation of evolving patterns of hominin behavior through time (Table 8.2).

A comprehensive study of the handaxes—and where appropriate their accompanying assemblages including flakes, flake tools and cores, primary and secondary working analysis and raw material considerations—can be found elsewhere (Cole, 2011, 2015*a*).

The method of analysis for handaxes follows the by-eye methodology described in McNabb et al. (2004) and McNabb and Sinclair (2009) that has been deemed useful in identifying broad behavioral trends within the dataset (Cole, 2011, 2015*a*, 2015*b*) that are in line with the aims just given. Although there have been criticisms of this methodology (Machin & Mithen, 2004; Underhill, 2007), they have mostly focused on the subjectivity of the system of analysis in regards to the fine-grained data scrutiny required for studying biface symmetry within tightly constrained time periods and the desire for a metric quantification of symmetry. However, McNabb (McNabb & Sinclair 2009) raises a cogent point that if the deliberate imposition of symmetry on handaxes was important to the original knappers, then their appreciation by eye would have been the method through which they judged the results. A simple eyeball test of symmetry would therefore reflect this process (McNabb & Sinclair, 2009) and be more

Table 8.2 **Total number of handaxes examined from each site arranged in chronological order**

Site	*MIS stage*	*Handaxe Count*	*Date Reference*
High Lodge	13	15	Ashton et al., 1992
Warren Hill	13	548	Hosfield, 2011
Elveden	11	44	Ashton et al., 2005
Hoxne Upper Industry	11	24	Ashton et al., 2008
Broom Pits	9–8	912	Hosfield & Chambers, 2009
Cuxton	8–7	186	Wenban-Smith et al., 2007
Pontnewydd Cave	7	58	Aldhouse-Green, 1998
Lynford	4–3	51	Boismier et al., 2012
Total	–	**1838**	–

MIS, Marine Isotope Stage. For the site of Cuxton numbers, refer to the Tester Collection held by the British Museum, Franks House.

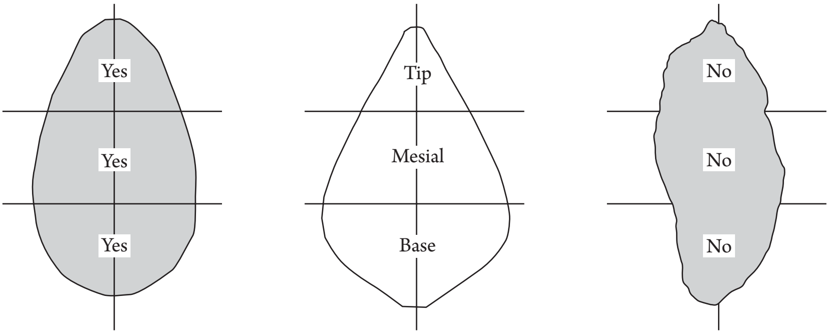
than sufficient to highlight a broad behavioral trend in the data should such a pattern present itself. Furthermore, although observer bias between more than one individual is acknowledged by McNabb (personal communication) and Underhill (2007), single-observer consistency is high for the data presented for this discussion (Cole, 2011, 2015*a*).

Within this methodology, symmetry is determined by dividing the artifact into three equal sections along the long axis on both faces (Figure 8.1). Each horizontal third of the artifact is "mentally folded over" to determine whether the edge outlines are symmetrical around the line of the long axis, and a simple "yes" or "no" score recorded. The artifact is then categorized by the three scores (for the tip, medial, and base) and assigned to a symmetry category based on the eight possible combinations of scores.

A further category was identified in McNabb et al. (2004, p. 658) and, where appropriate, shown within the results presented below:

- Parallel distinctive features along the margin—where there are visually distinct features located in parallel along opposite edges of the artifact, such as notches or trimmed concavities.

Using such a methodology to assess the imposition of symmetry on handaxes, researchers are able to compare the degree of symmetry both within and between assemblages. Such a comparison is a test of the long-held assumption that symmetry within handaxe manufacture becomes more marked over time (Hodgson



Classification	1	2	3	4	5	6	7	8
Tip	Yes	Yes	Yes	No	No	No	No	Yes
Mesial	Yes	Yes	No	Yes	No	No	Yes	No
Base	Yes	No	No	Yes	Yes	No	No	Yes

Figure 8.1 Illustrating handaxe symmetry and schema for recording. The gray handaxe outlines represent real examples from the Warren Hill assemblage stored at Frank's House, The British Museum. Image adapted after McNabb et al. (2004, p. 659, figure 5).

2015; Saragusti et al., 1998), indicating that handaxes became increasingly important in mediating hominin social behavior (e.g., Kohn & Mithen, 1999).

Results

Table 8.3 assesses the regularity of imposed form through symmetry on the handaxes over time, as per Table 8.2, and illustrates that, in contrast to widely held beliefs (e.g., Hodgson, 2015), completely symmetrical handaxes (those classed in the "yes, yes, yes" category) do not seem to have held a strong degree of significance for the knappers within any of the assemblages examined for this discussion. The knappers were clearly capable of producing fully symmetrical handaxes; however, the frequency of occurrence within each assemblage through time remained at a consistently low level (less than 8% of any assemblage). This in turn would indicate that the imposition of perfect or true symmetry on handaxe form was not a particularly important factor in handaxe manufacture. Furthermore, the degree of fully symmetrical handaxes for each assemblage does not appear to follow a clear chronological patterning. Rather, they seem to fluctuate randomly from 0% to a maximum of 7.8% of the assemblage across the whole dataset (Table 8.3). The only site that may possibly show an increase in the presence of symmetry comes from the Neandertal site of Lynford (Boismier, Gamble, & Coward, 2012) with an absolute symmetry total of 7.8% (Table 8.3). However, this still represents a relatively small percentage of the overall assemblage and is only 1% more than the site of Warren Hill (a significantly older Acheulean site) at 6.8% total symmetry. Therefore, although there can be said to be a small increase in symmetry at Lynford in comparison to the other sites examined in Table 8.3, it is unlikely to constitute a significant behavioral or cognitive change through time as described so often in the literature (e.g., Ambrose, 2001; Saragusti et al., 1998).

Discussion

As has been previously stated, conventional belief dictates that the imposition of symmetrical form on handaxes was an important component of handaxe production and significantly increased in occurrence through time as greater degrees of social meaning and cultural communications were associated with handaxe production (Ambrose, 2001; Foley & Gamble, 2009; Hodgson, 2009; Kohn & Mithen, 1999; Saragusti et al., 1998). This, in turn, according to the identity model, would have suggested that the Acheulean and Middle Palaeolithic hominins were capable of practicing a minimum third- to fourth-order of intentionality through intex perpetuation within a collective identity.

However, from the data summarized here and presented elsewhere (Cole, 2011, 2015*a*, 2015*b*; McNabb & Cole, 2015), it would appear that symmetry plays a relatively minor role in handaxe production (less than 8% of any assemblage). Moreover, symmetry does not significantly increase in presence through time and, where present, appears to be randomly distributed. Furthermore, all assemblages tended to demonstrate a wide range of tip shapes, suggesting that that there was no real preference on a cultural level for particular handaxe morphologies beyond a broad preference for general convergence, where the tip is only broadly convergent in shape with no consistent final form (Cole, 2011, 2015*a*, 2015*b*).

Therefore, it would seem that the handaxes in this dataset do not correspond to a model for the imposition of symmetry, nor is there an expression of preference for particular tip shape morphology. Rather, the data seem to resemble the "mental constructs" of Ashton and McNabb (1994), where the shape of the handaxe was a fluid idea in the mind of the knapper depending on individual ability, raw material constraints, function, time, place, and circumstance. The variety of tip shapes present within the dataset (reflected here by the lack of symmetry present in the top third of the handaxe and from data presented elsewhere) indicates that the hominins were certainly attending to a range of potential handaxe morphologies, and McNabb et al. (2004) and Cole (2011, 2015*a*) show that there may be potential indications for some degree of normalized

Table 8.3 **A broadly chronological relationship between sites and the variability of symmetry present within handaxe morphology. The "yes" and "no" categories relate to those seen in Figure 8.1**

	Symmetry by Eye									
	yes, yes, yes (%)	*yes, yes, no (%)*	*yes, no, no (%)*	*no, yes, yes (%)*	*no, no, yes (%)*	*no, no, no (%)*	*no, yes, no (%)*	*yes, no, yes (%)*	*Pdf (%)*	*Total (%)*
High Lodge *N = 15*	.0	6.7	20.0	33.3	.0	40.0	.0	.0	.0	**100.0**
Warren Hill *N = 548*	6.8	10.4	10.0	8.0	8.0	49.6	3.8	2.7	.5	**100.0**
Elveden *N = 44*	2.3	2.3	15.9	9.1	6.8	59.1	.0	4.5	.0	**100.0**
Hoxne Upper Industry *N = 24*	.0	12.5	12.5	8.3	8.3	54.2	4.2	.0	.0	**100.0**
Broom Pits *N = 912*	4.3	6.3	10.2	8.0	5.7	60.2	3.1	2.3	.0	**100.0**
Pontnewydd Cave *N = 58*	1.7	3.4	19.0	3.4	.0	72.4	.0	.0	.0	**100.0**
Cuxton *N = 186*	2.7	5.4	17.2	.5	1.6	69.4	2.2	1.1	.0	**100.0**
Lynford *N = 51*	7.8	7.8	5.9	13.7	7.8	45.1	7.8	3.9	.0	**100.0**
Total *N = 1838*	**4.7**	**8.1**	**13.1**	**6.3**	**5.6**	**56.3**	**3.8**	**2.1**	**.1**	100.0

Pdf = Parallel distinctive features.

pattern in handaxe shaping or secondary working. However, this may relate to the McNabb et al. (2004) notion of "conceptual standardization" based on "individualized memic constructs"—where the notion of the handaxe was socially generated and sustained within a group even though the final form was not determined through strong social imposition or strong social learning. A suitable alternative view may be to follow the McNabb et al. (2004, p. 667) suggestion that handaxe morphology was the result of "creating and manipulating chains of sequentially related routine actions," rather than a strong culturally mediated reduction strategy.

If it is accepted that a lack of symmetry represents an absence of intex perpetuation (no use of handaxes in culturally mediated social signals) and therefore, potentially, that their makers lacked third-order intentionality (as per the identity model), the question arises as to what the cognitive potential of the hominins involved may have been. Returning to the concept of a theory of mind and orders of intentionality stated earlier, I proposed that a theory of mind marks a necessary step in the development of abstract thought and symbolic construction through the conscious conception of a mind that is separate and distinct to one's own. Similarly, I would suggest that the McNabb et al. (2004) notion of "conceptual standardization" in handaxe form would also indicate an ability to conceive of a fluid abstract tool form in the mind's eye and to impose that form onto a handaxe blank through a series of related routine actions. This in turn could imply that the hominin handaxe knappers had a theory of mind or second-order intentionality—at a minimum—in order to be able to form a mental construct or a notion of conceptual standardization (as examples of abstract thought). If so, why did they apparently not then take the extra cognitive leap and utilize handaxes within social signaling?

One possibility may be that the lack of full standardization or symmetry in handaxe manufacture may indicate that the hominin knappers imitating their contemporaries never quite realized what it was that their contemporaries were envisaging in relation to handaxe form. The knapper's themselves had a clear concept of a handaxe; they may not, however, have fully understood that their contemporaries also had the same concept. This is perhaps unlikely given the range of handaxe morphology across the Old World on a variety of raw materials. When we examine a handaxe, we are seeing the behavioral and technical skills of hominins who were able to knap the same artifact through a range of physical and social situations, and, although the form remained a fluid concept, they must have been able to recognize the technological processes that their contemporaries were knapping a handaxe even if the final forms were non-standardized. Therefore, I suggest it more likely that the hominins were fixed within a realized second-order of intentionality or theory of mind, locked into the so-called *Acheulean gaze* (Foley & Gamble, 2009) of attending to handaxe form imposition. What they did not always do, however, was make the leap to third-order intentionality and realize the full potential of the Acheulean gaze to consciously off-load social communications and culturally meaningful symbols onto the material culture with which they interacted. This is a conclusion that may have some neurological support based on the recent work and conclusions of Stout and Chaminade (2012).

If this premise is accepted, then the evidence offered here and in more detail elsewhere (Cole, 2011, 2015*a*, 2015*b*) may indicate that, on a broad behavioral level, the hominins involved were limited to a second-order of intentionality and a notion of an internal and external identity bound to iconic and indexical sign reading and signaling. However, there are some important limitations to note: this observation is based on the apparent absence of evidence pertaining to a notion of perpetuated intex/symbolic sign propagation (through the lack of symmetry or significant standardization in tool form) and formulated on only one artifact type: handaxes. The question of organic artifacts and their role in hominin behavior from this deep period of antiquity may perhaps forever elude us, but their evidence is likely to be crucial in bearing out our behavioral assumptions of hominin species based on one medium of artifact manufacture.

Furthermore, the presence of what may be thought of as extraordinary artifacts such as giant handaxes within a small sample of Acheulean assemblages (Kelley, 1959) throws up the intriguing prospect of the ways in which individual artifacts within assemblages may carry more social weight than their counterparts, although it should be noted that the exact role of the so-called giant handaxes and their role within wider Acheulean assemblages is still unclear and in need of further work. Similarly, the question of specific variants, such as the twisted ovates known from MIS 11 (White, 1998) or the handaxe pairs from Boxgrove and Foxhall Road (Hopkinson & White, 2005; Pope, Russel, & Watson, 2006; White & Plunkett, 2004), also offer up intriguing possibilities for handaxe use in social signals. Perhaps what we are seeing with such individual extraordinary artifacts (if indeed they are extraordinary) are localized, independent innovations in which hominins on the border of third-order intentionality made a specific link with material culture and its potential symbolic role within mediating social relationships that, for whatever reasons—probably linked to small group sizes with weak or fragile social networks between groups (Gamble, 2013, pp. 92–107)—are not taken up at the broader species level of behavior. Whatever the longevity of such individual innovations (and we really do have no idea), it seems that from a broad species-level behavioral view offered here, the majority of Acheulean handaxes remained within the functional rather than the social, sphere (Cole, 2015*a*, 2015*b*).

Therefore, the question still remains as to whether it is possible to identify a clear point in the Palaeolithic record at which material culture is being produced at a third-order of intentionality. Around 300 kya, there was a fundamental technological shift in tool-making from hand-held tools (e.g., the

Acheulean) toward prepared-core technologies and composite tools—these are tools that were hafted and made of multiple components (Barham, 2010; Barham & Mitchell, 2008; Wadley, Hodgskiss, & Grant, 2009; Wynn, 2009). In defining "composite" here, I follow Barham (2010, p. 374) where the stress is on integrating different materials with distinct properties to create a single tool. In reference to prepared-core technology artifacts, there is no suggestion that every flake produced as a result of prepared-core technology was utilized within a composite tool, although there are clearly specific prepared-core technology tool morphologies that were seemingly intended for inclusion within a composite suite, such as retouched Levallois points. What is significant is that the technique of prepared-core technology allowed, for the first time, the repeated controlled technological production of flakes that were regularized in size and shape (as a result of technological influences and not necessarily cultural influences) resulting in a detached piece that would be more conducive toward inclusion within a composite approach.

As Barham (2010) highlights, Acheulean artifacts are dependent on a linear reductive process to produce final tool morphology, whereas prepared-core technology artifacts have the potential to be involved within a hierarchical additive process transforming a number of distinct components into a previously inconceivable tool form, the composite. This in turn suggests a shift in cognitive ability in which prepared-core technology artifacts "signal the implementation of planning, social learning, and a high level of imagination and intentionality . . . to conceive (of) tools made from multiple components" (Barham & Mitchell, 2008, p. 219).

Furthermore, in order to conceive of a composite tool, the creator must have an understanding of a minimum of three to four separate and distinct raw materials and how they work together (Barham & Mitchell, 2008; Wynn, 2009). This in turn suggests a conscious understanding of the separate *chaîne opératoires* that must be performed for each composite element before each can be combined into a single tool. For example, in preparing a haft from a range of available raw materials (such as wood, bone, antler, or horn), a binding agent such as a mastic or twine (or both) must be correctly prepared (heating, reducing, processing) in relation to the intended use, and the inserts for the composite tool must also be manufactured from a further range of raw materials (such as stone, bone, antler, or horn) with each raw material requiring a particular manufacturing or reductive process (Barham, 2010; Wadley et al., 2009; Wynn, 2009). Finally, once all the separate components for the composite tool creation have been processed through their separate *chaîne opératoires*, the hominin must then combine all the product results together in the correct order and at the correct time. Essentially, to create a composite tool, a range of specialist knowledge bases for each composite component (with all their individual cognitive challenges) must be combined together through an overarching single *chaîne opératoire* in the mind of the composite creator (Barham, 2010). It is this bringing together of three to four distinct *chaîne opératoires* and separate raw materials of varying physical properties to form a single tool through a process of hierarchical creation (Barham, 2010) that distinguishes and elevates the cognitive development of prepared-core technology over that of the Acheulean.

In terms of linking the cognitive requirements of composite tool manufacture to the identity model, I suggest that a third-order intentionality threshold at minimum is required. This third-order intentionality threshold may be related to the number of distinct *chaîne opératoires* that can be successfully held and then combined within an individual mind. However, it is also the increasingly complex social interactions and coordinations that need to be managed in order to combine three to four distinct *chaîne opératoires* successfully into a single artifact of material culture. Composite tool manufacture would require and result in a distribution of social expertise through the transmission of raw material manipulations and through the multiple *chaîne opératoires* between multiple individuals within the group (Barham, 2010). In order to keep track of such complex social organization and coordination, a minimum of third-order intentionality (and possibly even fourth-order) must be in play. Each individual engaged in the task of completing one *chaîne opératoire* must have a full understanding *and* working knowledge of not only the other *chaîne opératoires* involved in the sequence of manufacturing a composite tool, but also of the mental states of the individuals engaged within the distinct *chaîne opératoires* of the composite sequence. This mental understanding would be crucial in order to combine the separate organic and inorganic components in the correct order and at the correct time to successfully create the composite.

Even if it is assumed that only one individual (isolated from having to engage with the mental states of his contemporaries) is involved in creating a composite, a third-order of intentionality at minimum is still required. In order to create a composite tool, an individual must first envisage the tool in his or her mind as a mental construct; next, the individual must then mentally visualize and enact each process involved within each distinct *chaîne opératoire* and then combine them all together as a single tool in the correct order at the correct time. In order to form a mental construct of a tool, I have suggested that a second-order of intentionality is required, for example, to produce the Acheulean. However, the ability to mentally follow the hierarchical processes involved in manipulating three to four distinct raw material bases through three to four physically different *chaîne opératoires* and then combine them to create the original mental construct of the desired tool would require a third-order of intentionality at least. If this process is then included with a social or group context, then a fourth-order of intentionality may be required to coordinate the creation of such tools in line with the behaviors of other group members.

Whether engaged with as a collective or individual task, the combination of multiple raw materials (organic and inorganic) into a single artifact would provide a focal point for knowledge transfer and the development of cognitive understanding through shared experience (Barham, 2010; Grove & Coward, 2008; Iacoboni & Mazziotta, 2007) and, I would add, a sense of collective purpose and realized commonality of understanding, all of which could be mediated through complex systems of visual display and vocal utterance that would require a third- to fourth-order of intentionality simply to work.

If it is accepted that a minimum of third-order intentionality is required to construct a composite tool, and composite tool presence is mostly inferred from the presence of prepared-core technology within the Palaeolithic record, then the existence of prepared-core technology flakes or cores within an assemblage should indicate that the hominins involved had achieved a conscious and consistent third-order intentionality. As has been stated earlier, within the identity model, a minimum of third-order intentionality is required to utilize material culture within social signaling through a perpetuated intex (Cole, 2012, 2014*a*, 2014*b*, 2015*b*). However, just because a cognitive potential has been realized in one area does not necessarily mean that it was realized in another. So the challenge therefore is to identify where there may be signs of the use for perpetuated intex or visual display within the Palaeolithic, if it is accepted that perhaps handaxes are not those signs at a broad species level of behavior.

When discussing the term "visual display" in the context of Palaeolithic hominins, the train of thought tends to move toward body ornamentation and the subsequent evidence for such an act. Similarly, when discussing the question of body ornamentation within a Palaeolithic context, given the limited evidence for such an act across such a large time depth, focus falls on two main vehicles: beads or jewelry and pigment use. As of the time of writing, the incontrovertible use of beads as a system of personal adornment (a prime example of perpetuated abstract) within a securely dated context have almost exclusively been associated with modern humans (Botha, 2008; d'Errico et al., 2005, 2009; Henshilwood, d'Errico, Vanhaeren, van Niekerk, & Jacobs, 2004; Kuhn & Stiner, 2007; Kuhn, Stiner, Reese, & Güleç, 2001; Vanhaeren et al., 2006). Where beads or jewelry have been associated with non-*H. sapiens*, there is considerable uncertainty as to the anthropogenic modification of the artifacts or their contextual integrity and therefore their association with any species other than *H. sapiens* (e.g., d'Errico et al., 2003; d'Errico, Zilhao, Julien, Baffier, & Pelegrin, 1998; Kuhn & Stiner, 2007; Radovčić, Sršen, Radovčić, & Frayer, 2015; Zilhao & d'Errico, 1999). Even recent advances into the dating of cave art in Europe and, recently, Indonesia still leave open the question of whether non-*H. sapiens* could produce art (e.g., Aubert et al., 2014; Garcia-Diez et al., 2013; Wood et al., 2013). Subsequently, based on current evidence, when discussing the evidence for body ornamentation in relation to non-modern human species, we can only examine the use of pigments (e.g., Roebroeks et al., 2012) to any degree of certainty in terms of association, and the discussion shall proceed accordingly. However, future research and clarification on the use of beads and jewelry by non–*H. sapiens* species is not only welcome, but may require the addition of these species (such as the Neandertals) into the following discussion in regards to the perpetuated abstract.

Evidence for anthropogenically modified pigment use in the Palaeolithic is scarce and tends to range in dates from 300 to 170 kya, spanning a variety of geographical regions such as France, the Netherlands, the Czech Republic, India, South Africa, Zambia, and Kenya (see Barham, 2000, 2002, 2010; Barham & Mitchell, 2008; Roebroeks et al., 2012, for useful bibliographic summaries). It is interesting to note the current archaeological chronological correlation in dates between the use of pigments and the emergence of prepared-core technology (although this may be more a reflection of our current understanding or research bias of the Palaeolithic record or artifact collection rather than a genuine pattern of behavior). Unlike beads, pigments may have had uses beyond the decoration of the body, such as medicinal, a preservative in hide processing, or as an element in making adhesives for composite tools (Barham, 2002, 2010; Kuhn & Stiner, 2007; Roebroeks et al., 2012; Wadley et al., 2009) with the use of pigments within body ornamentation potentially arising out of a primarily functional role. However, use of iron minerals as pigments incorporated into degrees of signaling behavior have historically been of primary rather than secondary purpose (Barham, 2002; Knight, Power, & Watts, 1995). Therefore, when anthropogenically modified (such as rubbings or striations) pigments are found within the archaeological record, their use within systems of culturally meaningful visual displays that incorporate the body must not be immediately dismissed.

Therefore, in order to answer the question when did material culture become incorporated within systems of social communication at a broad species-wide behavioral level, I would suggest that the answer must lie with the advent of prepared-core technology circa 300 kya. With the innovation of prepared-core technology and composite technologies, a third-order of intentionality must have been realized on a cognitive level. Only with a third-order of intentionality may material culture or behavioral acts potentially become imbued with the culturally significant systems of social communications required to perpetuate the intex within a collective identity expressed within the identity model. The co-occurrence of prepared-core technology and pigment use may be related through a primarily functional link (e.g., Wadley et al., 2009); however, more research into differentiating functional versus symbolic use of pigments would prove most interesting in understanding the linguistic and cognitive abilities of the prepared-core technology hominins. Table 8.4 provides a technological and behavioral framework through which the Palaeolithic record may be related to the identity model and inferred cognitive complexity through orders of intentionality. Such a framework is intended here as a guide for researchers to engage with the technological outputs of hominin behavior (i.e., stone and organic artifacts) in such a way that facilitates understanding of hominin behavior and cognition beyond technological reconstructions of reductive knapping strategies and additive *chaînes opératoires*.

Conclusion

From the results presented briefly here and elsewhere (Cole, 2011, 2015*a*, 2015*b;* McNabb & Cole 2015), it would seem that, contrary to widely held belief, symmetry as a marker of culturally mediated artifact manufacture in handaxe production does not seem to increase over time or indeed to relate to overall handaxe form—at least within this dataset. This may suggest that symmetry was not a significant factor in handaxe production for the hominins represented here and that the majority of handaxes examined may not have been incorporated within systems of social communication, as has often been presumed (Ambrose, 2001; Foley & Gamble, 2009; Kohn & Mithen, 1999; Mellars, 1989, 1991; Ronen, 1982).

Therefore, the potential role of handaxes as markers of hominin behavior and cognitive ability, often measured against the degree of standardization present in artifact form or assemblage typology, must be reassessed—or at least the way modern researchers approach this topic. Perhaps Acheulean hominins did not view standardization or the imposition of symmetry on tool form in the same way that modern humans do; indeed, why would they? These ancient hominins have brains that are shaped and wired differently to ours; they are smaller, and their lifeways and environments are dramatically different from our own world experiences. Therefore, it may well be unfair of us to assume that symmetry or standardization in artifact production should play a significant role in hominin social signaling when we are dealing with nonhuman species whose views of the world and their position in it would be drastically different from our own.

The evidence offered here may indicate that, on a broad behavioral level, the Acheulean hominins involved were limited to a second-order of intentionality and a notion of an internal and external identity bound to iconic and indexical sign reading and signaling, with the proviso, however, that there may well be occasional Acheulean groups independently making innovative cultural and symbolic links with their material culture (e.g., giant handaxes, S-twists, handaxe pairs) to mediate social relations. These innovations seem to be localized and fail to transcend to the broader species behavioral level, probably as a result of small populations with poor social networks and a cognitive level that fluctuates between the second and third orders of intentionality.

Table 8.4 **A behavioral and cognitive framework linking the identity model to the archaeological record.**

Technological Mode	*Material Culture Description*	*Behavioral Implications*	*Social Communication*	*Category of identity / order of intentionality*
1 (including the Lomekwian)	• Deliberate lithic tool production to create specific edges for use. • No standard form imposition, tool shape largely governed by raw material size, shape, and mechanical flaking properties. • Consists of pebble tool industries dominated by small flake removals (<10 cm) and chopping tools (Oldowan). • Possibly bone or wood tools that have limited evidence for anthropogenic modification.	• Hominins have a realized sense of self, which compliments the egocentric goal-directed behavior reflected in the strategies of tool production. • Evidence for some forward planning in raw material procurement. Social communications governed by egocentric, dyadic, gestural, and attention-directed auditory signals with a presumably greater repertoire than extant primates. • The beginnings of imitative learning may be evidenced here.	• Similar to that of extant primates tending to be egocentric, context-specific, and dyadic non-ToM social communications. • The body is used in sexual selection through visual display perhaps with an increased propensity for female choice (due to reducing levels of sexual dimorphism) in mate selection within a predominantly polygynous mating strategy.	• Internal/1st

2	• Lithic tools predominantly based on large flakes (>10 cm) or bifacially reduced cores. • Consists mostly of bifacially knapped handaxes and cleavers (large cutting tools [LCT])—the Acheulean, although flakes, flake tools, and cores still being produced. • Regional variation in shape and form primarily affected by raw material. • Deliberate imposition of shape and form to LCTs evidenced through the presence of a mental construct in regards to LCT form with a degree of conceptual standardization.	• Hominins have a theory of mind (ToM) that marks the beginnings of abstract thought reflected in the imposition of deliberate shape and form on lithic artifacts through the mental construct notion. • Evidence for goal-directed behavior associated with greater planning capabilities and complex imitative social learning, organized hunting, and controlled use of fire. • Group organization reflecting complex social communications grounded in visual display.	• With the attainment of a ToM, the body becomes a focal point for socially significant triadic visual display and gesture possibly accompanied by limited vocalization. • Complex imitative learning focuses on the body where individuals acquire the ability to recognize familiar actions performed by an "other" and are able to repeat or perform novel actions constructed from a familiar repertoire. • Visual display and social signaling are direct and context-specific. • The body plays a reduced role in direct sexual selection evidenced through a reduction in sexual dimorphism. Reflecting a higher degree of female choice and an increasing importance in material culture?	• Internal / 1st • External / 2nd

(*continued*)

Table 8.4 **Continued**

Technological Mode	*Material Culture Description*	*Behavioral Implications*	*Social Communication*	*Category of identity / order of intentionality*
	Final LCT form remains a fluid concept with no evidence for an increase in artifact symmetry or standardized form through time. • Some organic artifacts may be in use (e.g., wooden spears for hunting).			
	• Individual groups may produce artifacts of extraordinary design, such as giant handaxes, S-twist handaxe, handaxe pairs, symmetrical handaxes(?).	• If assemblages have a definite bias toward "true" symmetry or contain artifacts of "extraordinary design" (e.g., giant handaxes) then it may be that such artifacts have an implication beyond the purely functional and may hold some social or cultural significance.	• The body and material culture begin to play a more pronounced role in identity perpetuation broadcast social signals on a context-independent and individual to individual (and individual to group?) basis.	• Internal / 1st • External / 2nd • Intex / 3rd • Perpetuated Intex / 3rd

	• Toward the end of Mode 2 (later Acheulean), an element of PCT may enter the archaeological record, although there is still a strong emphasis on large flake production and bifacially reduced cores.	• If there is the presence of PCT and composite tools within Mode 2 assemblages then perhaps there is a more sustained cognitive breakthrough beyond a ToM.		
3	• A shift from producing lithic tools from cores and flakes, to preparing cores to extract flakes of a particular form (PCT). • PCT (e.g., Levallois) focus on producing standardized flakes with the potential for later modification (e.g., into points or handaxes).	• Hominins have a commonality of understanding (cultural affinities) and a clear sense of shape and form that begin to play a role beyond the purely functional. • The capability to produce composite tools displays an ability for abstract thought beyond a functional level, which may manifest itself in the beginnings of cultural influences seen within the archaeological record, such as the use of pigments.	• The body has a central role in social communication, becoming a transmitter and receiver of social information centered around visual display and manual gesture accompanied by vocal utterance. • The body also plays an important role in identity perpetuation, the social boundaries of the body begin to be extended through material culture and behavioral display. Visual display and social signaling may begin to be indirect and context independent. • Material culture remains predominantly functional within this category, although pigment use may suggest an additional nonfunctional use for material culture reflecting complex visual displays with culturally significant social signals.	• Internal / 1st • External / 2nd • Intex / 3rd • Perpetuated Intex / 3rd • Collective / 4th

(*continued*)

Table 8.4 **Continued**

Technological Mode	*Material Culture Description*	*Behavioral Implications*	*Social Communication*	*Category of identity / order of intentionality*
	• This type of lithic production also indicates the presence of composite tools. • Regional variation possibly driven by cultural influences rather than raw material, although raw material may still govern shape and size of artifact to a certain degree. • Use of organic material culture for composite tool creation.	• Artifacts maintain a predominantly functional significance but may carry social meaning in regards to the creator or group. • Social communication is centered around complex gesture and utterance incorporated within visual display.	• Sexual dimorphism reaches levels similar to modern humans, indicating a greatly reduced role of the body in direct sexual selection possibly indicating active female choice in mate selection with an emphasis on skilled visual display and material culture as selection drivers.	
4–5	• Continued emphasis on flake production with a predetermined shape and form.	• Hominins have a commonality of understanding, a clear sense of shape and form, and the capacity for fully symbolic and functional abstract thought evidenced through the presence of nonutilitarian and composite material culture and behaviors (such as burial).	• The body maintains a prominent role in social communication as a transmitter and receiver of social information centered around visual display (enhanced through bodily ornamentation), manual gesture, and grammatical language.	• Internal / 1st • External / 2nd • Intex / 3rd • Perpetuated Intex / 3rd • Collective / 4th • Abstract / 5th • Perpetuated Abstract / 5th

• Flake blanks within this category are primarily concerned with composite tool production with limited secondary shaping. • Use of organic material culture for composite tool creation. This category includes an expanded repertoire of complex bone tools (such as harpoon heads). • In addition, material culture with a purely nonutilitarian design enters the record in the form of ornamentation (beads), art, and figurines (humanoid and anthropomorphic). • Clear evidence for regional variation in material culture production on a cultural basis.	• Social communication is centered around visual display, gesture, and grammatical language. • Artifacts carry social meaning in relation to the creator and user (individual and group) and are now fully complicit in identity propagation.	• The body's boundaries are now fully extended through material culture (through ornamentation, figurines, art, and tool production) on an individual and group basis with material culture adopting a functional and symbolic role. Visual display and social signaling now completely indirect and context independent. • The body plays a full role in identity perpetuation through visual, vocal display, and material culture. • The body may play a more important role in sexual selection aided through ornamentation, although skilled visual display in material culture production may still play an important role.

At a more species-wide level of complex behavior, perhaps the significant behavioral and cognitive implications of prepared-core technology and composite tools coupled with the use of ochre occurring circa 300 kya offer a more reliable archaeological marker for the presence of a third-order cognizance (Barham, 2010; Cole, 2011, 2015*b*). By examining the archaeological record through the heuristic framework of the identity model, it would seem that the predictions of the social brain hypothesis, in terms of hominin cognitive abilities, do not quite match the behavioral evidence of the archaeological record if taken at the species level discussed here (see Cole, 2011, 2015*b* for a more detail discussion). Therefore, I would suggest that the social brain hypothesis predicts the potential cognitive ability of ancient hominin species, whereas the archaeology, through the filter of the identity model framework (Table 8.4), illustrates the realized cognitive ability. The two are not necessarily mutually exclusive, and it would appear that cognitive potential must be in place before it can be realized—which in turn suggests that physiological changes must occur before behavioral ones. Researchers producing cognitive models for the Palaeolithic and seeking to test those models against the behavioral record must therefore be prepared to take the differences between potential versus realized behavioral levels into account.

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9

Bootstrapping Ordinal Thinking

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Introduction

Paleoanthropology has long championed a biocultural perspective on human evolution in which biology and culture are seen to have evolved together to produce the modern human condition. Most paleoanthropological accounts of evolutionary mechanism, however, remain fairly straightforward Darwinian models elaborated with ecological and demographic insights. In such models, biology–culture co-evolution occurs via selection for cultural capacity. In the narrower domain of cognitive evolution, the interrelationship between culture and biology, especially via technology, has been a tantalizing but poorly explored area of research. Are there components of human cognition that evolved specifically in response to human culture? It certainly seems as if there should be; after all, extensive reliance on culture is one of the things that distinguishes us from our primate cousins. Yet the literature remains frustratingly vague. Dunbar and colleagues (Dunbar, Gamble, & Gowlett, 2014) have proposed theory of mind as a response to complex social life, with Cole (2014 and Chapter 8, this volume) proposing a role for handaxes in the evolution of second- and third-order levels of intentionality. Recently, Overmann has explored the material basis of numerosity (2013, 2015, and Chapter 5, this volume) and literacy (2016), but there are few other examples that integrate a *specific technology* with a *specific cognitive ability* and its *neural substrate*. In this chapter, we propose to do just this by describing how a narrowly circumscribed cognitive ability—conceiving of ordinal sequences—could have evolved relatively quickly via embodied and extended cognition and the developmental process of neuronal recycling.

The Extended Mind

Cognition does not happen just in the head; it employs and thus in some sense includes the physical resources of bodies and artifacts. This is the core realization of the perspective in cognitive science known variously as the embodied/situated/extended mind (Clark, 1997; Malafouris, 2013; Robbins & Aydede, 2009; also see Chapter 4). One obvious example is the calculator; anyone can perform complex calculations (including calculus) using a handheld device. In a very real sense, this device makes its users smarter (i.e., able to solve problems they could not otherwise solve). The calculator is a recent and obvious example, but there are others, many of which have considerable antiquity. One example of such a device is the calendar, which enables its users to plan activities far in advance and remember activities performed in the past. In addition to external devices, there are in-the-head knowledge systems that enable users to take advantage of these devices, perform operations mentally, structure their understanding of environmental stimuli, act and interpret the actions of others in meaningful ways, and so on. Arithmetic, for example, is a cultural algorithm (i.e., a learned set of rules), and it in turn is based on yet another cultural algorithm, the formal number concept. Neither of these algorithms is natural, in the sense of pre-existing in the world waiting to be discovered; instead, both must be constructed and learned by an individual in a cultural context. Similarly, a calendar is a cultural algorithm that presupposes time to be structured as a divisible substance with a sequence of units that can be extended into the past and the future. And if these knowledge systems were not impressive enough on their own, they in turn rely on specific neurocognitive resources. In the case of number concept, these neurocognitive resources are subitization and magnitude estimation (Chapter 5; Coolidge & Overmann, 2012). In the case of calendars, there are two cognitive bases: *autonoesis*, the subjective feel for present, future, and past (De Smedt & de Cruz, 2011; Tulving, 2002), and *ordinality*, the arranging of sequences along a uniform dimension.

So where is the modern mind in these examples? Is it in the devices? In the knowledge systems? In the neural networks of the brain? Or in all of them together? Untangling these elements in an evolutionary sense is the key issue for understanding the evolution of the human mind.

Arguably, even the neurocognitive components of these systems developed and evolved via the extended resources of knowledge systems and artifacts. Malafouris (2008, 2013; Malafouris & Renfrew, 2008), for example, has made an elegant argument for how material social markers such as beads could act as scaffolds for extending a concept of self into the past and future—autonoetic thinking, the first of the two cognitive bases for calendric time. Simply, the temporal extension of beads enables the user to extend his or her self from the present into the past and future: "These special epistemic qualities emanate primarily from the ability of the beads, as material things attached to the body, to transform the phenomenological self-as-subject to a social self-as-object" (p. 408). To put it another way, wearing beads today identifies this self as me; wearing the beads tomorrow or yesterday identifies the future or past self as me.

How material culture might have worked to scaffold the second neurocognitive component of calendric time—ordinality—is the focus of the following analysis.

Ordinality

Ordinality is an essential component of modern calendars, alphabets, and number concepts. The term has two related meanings. The more general meaning is the construction of or attention to invariant sequences of some kind (e.g., days of the week, months of the year, numbers, alphabets, and so on). The narrower meaning limits ordinality to numbers that can be arranged in terms of increasing cardinal value (e.g., Ischebeck et al., 2008). The following discussion will use the first, more general meaning of invariant sequence.

Evidence from cognitive neuroscience in the form of imaging studies, experiments demonstrating double dissociation, and an unusual condition known as synaesthesia suggest that the ability to represent ordered relations may be a comparatively coherent cognitive ability distinct from other components of quantitative thinking (Rubinsten & Sury, 2011). The basic ability to rank items in terms of size (a minimal ordinal relationship) is present in infants as young as 11 months and has been demonstrated in monkeys and even chicks (Lyons & Beilock, 2011; Rubinsten & Sury, 2011). Neuroimaging studies have established the intraparietal sulcus (IPS) as the locus of ordinal representations in both children and adults (Ischebeck et al., 2008; Kaufmann, Vogel, Starke, Kremser, & Schocke, 2009), and the IPS is also the location activated in numerical quantity judgments (Orban & Caruana 2014). There is some evidence that numerical sequences and alphabetic sequences activate slightly different locations of the anterior IPS, but this distinction is far from established (Rubinsten & Sury, 2011). There is also a tentative indication that the right IPS is more heavily activated in nonsymbolic number processing and the left IPS in symbolic numerical processing, but again this remains preliminary (Kaufmann et al., 2009).

Neuroimaging evidence is provocative. Not only does it reveal the close neurological contiguity for the processing of numbers and sequences, but it also links them closely with spatial cognition. However, this contiguity does not require that they be linked in a functional or evolutionary sense. Indeed, neuropsychological evidence suggests that the processing of numbers and sequences are separate: individuals with brain lesions demonstrate a classic double dissociation of cardinal value and ordinal judgments. Delazer and Butterworth (1997) describe a patient with an impaired ability to judge the cardinal value of numbers but who retained ordinal judging ability, and Turconi and Seron (2002) describe a patient with ordinal impairment who retained most quantitative abilities. As with neuroimaging studies, such neuropsychological evidence must be used with care, but these studies do suggest that ordinality and quantity judgments may have relatively separate neural bases.

The evidence for dissociation is further corroborated by a phenomenon known as *synaesthesia*, a neurological condition in which perceptual information from one domain leaks into percepts of another type—sounds evoking tastes, smells evoking colors, vision evoking smells. The most common forms of synaesthesia are *grapheme synaesthesia*, in which numbers or letters evoke colors (found in an estimated 4% of the population); *number–space synaesthesia*, in which numbers appear to occupy positions in space; and *day–month synaesthesia*, in which days of the week and/or months in the year evoke colors (see Cohen Kadosh, Gertner, & Terhune, 2012; Cohen Kadosh & Henik, 2007; Gertner, Henik, Reznik, & Cohen Kadosh, 2013; Novich, Cheng, & Eagleman, 2011; Simner, 2009, 2012).

The neurological basis of synaesthesia has not been clearly established, but many researchers believe that it results from an incomplete "pruning" of neural networks during cortical development, such that normally separate perceptual networks remain linked and able to "cross-talk" (Spector & Maurer, 2009). This cross-talk has been demonstrated in positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) imaging studies. When Tang, Ward, and Butterworth (2008) used fMRI to study individuals with number–form synaesthesia, they found that, for these individuals, ordinal tasks (which involve representing and recalling overlearned sequences) activated bilateral IPS regions that were slightly posterior to the regions activated by number value. In another fMRI investigation of synaesthetes, Pariyadath and colleagues (Pariyadath, Churchill, & Eagleman, 2008) found that the overlearned sequences activated regions of the right middle temporal gyrus, the right temporo-parietal junction, and the left inferior frontal gyrus.

The cross-talk between cognitive domains supplies a handy noninvasive tool with which to explore the nature of cognition (Cohen Kadosh & Henik, 2007). In essence, output from one neural network or neuronal group illuminates the working of a second, normally independent network, thereby revealing structure that is not otherwise apparent. Alphabets, numbers, days of the week, and months of the year all share one salient feature: they are all overlearned ordinal sequences (Eagleman, 2009). In synaesthetes, output from neuronal groups in the visual cortex "colors" overlearned sequences, revealing the existence of brain resources that facilitate sequential organizing. Note that it is not the values themselves that evoke color; rather, it is the ordinal positions. If there were no neural ordinal generator, there would be nothing for the neural cross-talk to color, and there would be no grapheme or day/month synaesthesia. Thus, one the most common forms of synaesthesia strongly indicates that the human brain is endowed with a neural mechanism for representing and recalling overlearned ordinal sequences.

Here is the odd thing about such overlearned sequences: they are not natural. Nothing in the natural human life-world or environment exists as an invariant sequence with elements that change uniformly according to some unidimensional value.[1] Days are constructs, months are constructs, numbers are constructs, and alphabets are constructs. This in turn suggests the tantalizing possibility that a specific neural network has evolved in service of a specific kind of cultural thinking.

Bootstrapping

Bootstrapping is a metaphor for a particular kind of cognitive development in which a more powerful cognitive system (CS2) is self-generated using a less powerful antecedent system (CS1). The classic example, discussed at length by Carey (2009), is children's construction of number concept. Children are born with innate abilities to judge small numbers (subitization) and compare larger quantities (magnitude estimation; Coolidge & Overmann, 2012). But they must learn numbers, and the manner in which they acquire this ability is quite revealing. They use the *words* for numbers as "placeholders" for the concept itself. Children first memorize the list of numerals, sometimes as high as twenty or more, without understanding the basic rule of cardinal value (1 + 1 = 2, 2 + 1 = 3,. . . n + 1 = x). These placeholders enable them to notice and think about numerical relationships. They learn that small numbers follow the cardinal rule, and eventually they realize that all numbers are constructed using it. Here, it is the lexical labels that act as placeholders, but material objects can also play this role. In US grade schools, it is common for teachers to use colored blocks of proportional length to teach basic arithmetic. The blocks act as placeholders for numbers as children explore the combinatorial possibilities and invariances. From this they construct concepts of addition and subtraction.

Much the same process must have underpinned the initial development of such concepts in the human past. In this context, however, lexical labels could not have acted as placeholders because the labels did not exist; similarly, labels for days of the week could not have existed prior to a concept of "week." When there are no pre-existing lexical labels or concepts, there are actually two avenues by which ordinality might have evolved—through embodied cognition using anatomical parts or through material extension.

Fingers

Developing the ability to count begins with making one-to-one correspondences between a reference set of objects and a set of objects to be counted. Fingers provide a particularly convenient reference set. Moreover, the ability to control precise movements of the fingers is neurofunctionally associated with the perceptual system for quantity; both are subserved by the IPS, making their interaction in counting cognitively prepotent. The close association of the perceptual system for quantity and finger movement has also been demonstrated in fMRI studies of children performing number tasks (Krinzinger et al., 2011).

Finger-counting is shared across cultures, regardless of the complexity of number systems (Crollen, Seron, & Noel, 2011; Overmann, 2013, 2014). Not all cultures use the same system, but all seem to function under similar neuromuscular constraints. Given the cross-cultural ubiquity of finger-counting, it appears likely that the use of the fingers for counting preceded the use of material devices like knotted strings, tokens, tally sticks, or stringed beads (for a more detailed discussion, see Chapter 5 and Overmann, 2013, 2015).

As quantification devices, fingers and the body are limited, functioning mainly to aid working memory in the moment. Their accuracy (ability to reproduce a quantity's actual value) is generally limited to values that can be counted using both hands, both feet, and arbitrary locations on the arms, legs, head, and torso. Their precision (ability to reproduce a quantity's value under different conditions) diminishes whenever something interrupts the counter's attention. Their capacity does not generally afford an ability to handle large or complex numbers, and they lack the ability to communicate across time or distance. Thus, as useful as such a system clearly is and has been, it is unlikely on its own to have been the scaffold for ordinality. Something else was needed.

Beads

Material devices provide a better avenue for bootstrapping an ordinal concept than do fingers. As discussed earlier, material objects can extend cognition, enabling the limited resources of one conceptual system (CS1) to construct a more powerful understanding (CS2). In the case of ordinality (CS2), the antecedent abilities (CS1) consist of core numerosity (subitization and magnitude estimation) and an ability to label. How could such limited resources lead to an ordinal concept? In the absence of an ordinal model, it would seem to be impossible (Fodor's paradox; see Carey, 2009): for example, how could one conceive of a calendar without an ordinal sequence as a model? A material scaffold provides a way around the impasse.

Ethnographic examples of such devices are fairly common. In the 19th century on the Southwestern Plains of the United States, the Comanche used tally sticks to transmit detailed route instructions to young men raiding into terrain unknown to them. Older, experienced men would sit the young men down around the fire the night before the raid and provide each with a stick. The experienced men would describe each landmark the raiders would encounter on their journey. For each change in direction the young men would be instructed to make a notch on the tally stick. The novices would then recite by feel what landmark each notch on the tally marker indicated, and they were expected to repeat the directions back until it was perfectly memorized (Dodge, 1883). Here, the notches on a stick acted as an ordinal mnemonic that helped the user recall a sequence of moves that had to be made in the proper order. In the modern world, beads can similarly act as extensions of cognition. *Ranger beads*, for example, are used by mountaineers and specialized military units to keep track of distance traveled on foot. In a typical example, a bead user will determine the number of his or her paces that equal 100 meters. When traveling, users can then count paces and pull down a bead every time they hit their 100-meter mark. This application of tally markers extends the users' working memory while navigating and provides a very accurate means of determining distance traveled. Skilled users can be accurate to within a few meters after navigating many kilometers using this system.

A string of beads is potentially more powerful than notched sticks or knotted strings because it materially instantiates three phenomena (CS1): a one-dimensional series, individuation of items, and an invariant sequence. Each bead occupies an unchanging sequential position along the dimension of the string, although there are two different sequences determined by the direction of movement. If the various beads have different sizes, shapes, or colors, the structure becomes a feral ordinal composition, with each bead occupying a unique, invariant place (until the string is broken). These qualities are inherent to the structure of a string of beads and do not require that the maker possess an ordinal concept. But stringing and manipulating beads enables anyone to *notice* and even *think about* certain relationships, with beads acting as placeholders, much as modern children use numerical labels. One of the relationships is one-to-one correspondence; beads on a string can be matched with items in another array. From this, a simple quantifying device—*without numbers* (i.e., like the rosary, which matches beads to prayers)—could be developed. It is also possible to attach labels to different beads, at which point the invariant sequence becomes a material ordinal device that could be used to track and organize other sequential phenomena (e.g., days). The labels could then become an overlearned sequence detached from the device itself; that is, a true ordinal concept.

Evidence for Beads in the Middle Stone Age

Our choice of beads as a primary example stems from a confluence of evidence and interpretations that emerged during investigations into the evolution of working memory capacity. The South African Middle Stone Age (MSA) boasts a number of sites that have presented the paleoanthropological community with the earliest evidence for a number of posited components of modern culture: bow-and-arrow at Sibudu (Lombard & Haidle, 2012), engravings at Diepkloof and Blombos Cave (d'Errico, Henshilwood, & Nilssen, 2001; Henshilwood, 2007), and, most famous of all, beads at Blombos Cave (d'Errico, Henshilwood, Vanhaeren, & van Niekerk, 2005; Marean, 2010; Vanhaeren, d'Errico, Niekerk, Henshilwood, & Erasmus, 2013). At Blombos, evidence clearly indicates that the beads were strung (Vanhaeren et al., 2013).

On the interpretive side, these beads, especially those from Blombos, have anchored arguments for symbolic culture, social marking, and language (d'Errico et al., 2003; d'Errico et al., 2005; Henshilwood, 2007; Henshilwood & Dubreuil, 2009; Henshilwood & Marean, 2003). Our own investigations into the evolution of modern working memory capacity (e.g., Wynn & Coolidge, 2010) emphasized other features of the archaeological record. However, more recently in our investigation into the evolution of numerosity (Coolidge & Overmann, 2012; Overmann, 2013, 2015; Overmann, Wynn, & Coolidge, 2011; Wynn, Coolidge, & Overmann, 2013; Chapter 5), we examined the possible uses of beads, including possible use as a counting device (Janulis, 2012). We determined that beads alone, even if strung, would not imply the presence of a true number concept because they would not require a cardinal rule ($1 + 1 = 2$, $2 + 1 = 3$ . . . $n + 1 = x$). However, strings of beads have a number of inherent features that make them provocative candidates for scaffolds of other cognitive abilities.

Bead use in the MSA was widespread, geographically and chronologically speaking, in Africa and the Near East (Bar-Yosef Mayer, Vandermeersch, & Bar-Yosef, 2009; Bouzouggar et al., 2007; d'Errico, Vanhaeren, & Wadley, 2008; d'Errico et al., 2009; Güleç, Kuhn, & Stiner, 2002; Henshilwood, d'Errico, Vanhaeren, van Niekerk, & Jacobs, 2004; Kuhn & Stiner, 2007; Lombard, 2012; Vanhaeren et al., 2006), so much so that the archaeological evidence warrants the claim that the manufacture and stringing of beads was regularly practiced for thousands of years. Moreover, beads were clearly a component of the artifact repertoire of the modern people who colonized Australia (Balme & Morse, 2006). Bead use in the MSA after 80 kya was common, if not ubiquitous—common enough for beads to be included among the everyday artifacts of human culture.

The Adaptive Value of Ordinality: Enhanced Planning and Structured Time

Why should ordinal thinking have acquired dedicated cognitive resources? Ordinality is a very useful organizational concept, especially for repeated or sequential phenomena. Instantiated through a simple string of beads or other material device, it could have solved a number of adaptive problems.

Some foraging strategies, for example, could have been made more efficient through the use of tally markers. Lyn Wadley and colleagues, for example, have argued that traps and snares were used during the time of the Howiesons Poort industry and perhaps the Still Bay industry in the South African MSA (Wadley, Hodgskiss, & Grant, 2009). One of us (KJ) has undertaken actualistic research in cooperation with primitive skills experts John McPherson to test the efficacy of such trapping systems. Results clearly suggest that acquisition of small mammals would have been greatly enhanced by a methodical harvesting strategy that incorporated an external mnemonic aid. In order to rely on food from traps, snares, or other "remote capture" systems, the devices must be employed in large numbers. Eight to ten traps is arguably the bare minimum when targeting small game such as rats or rabbits, with much higher numbers being required to reliably provide food on a day-to-day basis (McPherson & McPherson, 2003, p. 174). In order to make effective use of such traps, they must be moved frequently and checked daily in order to avoid overharvesting one area or spoiling meat that is not retrieved soon enough. Daily recall of the location of 10 or more traps in novel locations, and which by their nature are hidden from sight, would have stressed long-term and working memory capacity and been extremely challenging. Many modern trappers use cairns or markers left along paths of travel to indicate trap location. In effect, these act as a materially enabled one-to-one correspondence. If the trapper has a number concept, he or she can perhaps recall how many were set. Lacking a number concept of some kind, a tally marker would provide a very useful means of keeping track of numbers of remote capture systems. Thus, even in the absence of a number concept, material artifacts could have acted as a system of one-to-one correspondences and become a scaffold for more powerful ordinal concepts. Perhaps the most significant of these was a concept of time.

Our everyday concept of time is a cultural construct, invented as a means of solving problems related to the pastness and futureness of human experience. In essence, our understanding of time is a concept of "folk physics," invented when it became necessary for us to recollect an accurate passage of events in the past or to forecast an event or sequence in the future. In Western folk physics, for example, time is conceptualized as a linear succession of equivalent units that extends infinitely behind or ahead of us. Alternative systems (e.g., Mesoamerican) have equivalent sequences of units that repeat in cycles of some specified number or which are characterized by the vastness of their size. In either system—linear or cyclical—the structure of time relies on an ordinal sequence of units (actual space-time is quite a different phenomenon; see Einstein, 1916/2005).

Ordinality structures the conception of time, facilitating the ability to plan. Natural rhythms (circadian, seasonal) provide some structure to time, and many organisms have evolved mechanisms for exploiting such structure, but any activity that requires a different or more precise level of planning (scheduled foraging, for example) would benefit from a calendar of some sort. And the minimum requirement for a calendar is an invariant ordinal sequence of time units, which could be provided by an appropriate sequential artifact and one-to-one correspondence (e.g., a string whose knots represent lunar appearances). In the spate of recent publications on the evolution of the modern mind, the ability to "plan ahead" has often been emphasized, although more often than not the accounts lack any clear discussion of just what this entails in a cognitive sense. The ability to construct and use ordinal sequences is a planning tool that had obvious benefits in structuring future action. Moreover, it has a clear neurological basis. It is therefore an excellent example of a cognitive trait that co-evolved with human material culture to produce an enhanced problem-solving ability.

Bootstrapping Ordinality

To reiterate an earlier point, neural resources devoted to representing overlearned ordinal sequences are a rather odd evolutionary product. At the scale at which humans operate, the natural world appears to provide no such sequences, and hence, nothing that could select for a human phenotype sensitive to them. But several such overlearned sequences can be found in cultural constructs. There is, then, the likelihood that the neural circuitry for overlearned ordinal sequences co-evolved with material culture and that it is a product of the extended mind.

Various mechanisms of gene–culture co-evolution have been proposed, including niche construction (Kendal, Tehrani, & Odling-Smee, 2011), the ratchet effect (Tomasello & Herrmann, 2010; Tomasello, Kruger, & Ratnet, 1993), genetic assimilation (Hall, 2003), and the Baldwin effect (Baldwin, 1896; Depew, 2003). Neuroscience itself has developed models of learning and neural phenotypic change known collectively as "neural reuse" models. In neural reuse, "circuits established for one purpose are commonly exapted (exploited, recycled, redeployed) during evolution or normal development, and put to different uses, often without losing their original function" (Anderson, 2010, p. 246). One well-known example of neuronal reuse comes from reading. When children learn to read, the brain maps the visual inputs onto circuitry in the lateral occipito-temporal junction, a region now known as the visual word form area (VWFA). In different individuals, the VWFA has the same location and organization regardless of the orthographic system in use (e.g., ideographic or alphabetic); individuals who learn to read Chinese use the same basic neural resources as those who learn to read French. The brain region in question lies within the left occipito-temporal sulcus, very close to other shape recognition areas for faces and objects. Research with macaques indicates that the comparable areas of the nonhuman primate brain are devoted to shape recognition, with a posterior–anterior hierarchy of increasing sensitivity to complex shapes. Thus, the VWFA appears to have an evolutionary precursor in primate shape recognition neurons (Dehaene & Cohen, 2007).

Based primarily on this well-documented phenomenon, Dehaene and Cohen (2007) have proposed a specific mechanism for neural reuse, the *neuronal Recycling Hypothesis*,[2] to explain the process of neural localization in learning. This hypothesis posits that cultural acquisitions such as reading "find their neuronal niche" (p. 384). That is, the brain leverages circuits that have similar functions and which are sufficiently plastic to orient to slightly different inputs (in the case of reading, these are circuits in the form recognition area of the occipito-temporal cortex). Learning then maps the new inputs onto the older neuronal groups. Interestingly, the organization of the precursor network had an effect on the kinds of orthographic systems humans developed. Many orthographic systems are based in minimal units of one, two, or three strokes that are combined into more complex units, a limitation apparently imposed by the specific function of the neural circuits exapted for reading (Cantlon & Brannon 2007; Coltheart 2014; Tan, Laird, Li, & Fox, 2005).

Neuronal recycling is also a factor in learning quantitative abilities. Numbers and arithmetic calculation are processed by areas in the IPS, although in this case the function of the primate precursor is also devoted to numerosity, so the functional shift is not as dramatic. The number example is particularly pertinent to our interest because ordinality, too, engages IPS resources, although slightly posterior to those used in numerosity. In addition, the close neural proximity of number processing and spatial processing has been well-established (Tang et al., 2008) and has led synaesthesia researchers to suggest that there is a common neural substrate, found in everyone, in which sequential processing has exapted neuronal resources that initially evolved for spatial cognition: "brain areas that evolved initially for one cognitive function (e.g., representation of space) reuse these earliest existing structures during evolutionary development to acquire culturally-driven capabilities (e.g., representation of numbers)" (Gertner et al., 2013, p. 1360). Gertner and colleagues focus on the mental number line, an imaginary horizontal line progressing from small to large numbers that is influenced by such things as culture (e.g., reading direction and finger-counting habits) and handedness (Fischer, 2008). Of course, in evolution, a true number line could not have emerged prior to a number concept, but non-numerical sequences could have, enabled by a bodily or artifactual scaffold. The close neural proximity of finger-counting corroborates this particular co-evolutionary complex—spatial cognition, fingers, and overlearned sequences.

Neuronal recycling provides a provocative description of how learning can alter neural phenotypes, and, if added to a co-evolutionary mechanism such as the Baldwin effect or C. H. Waddington's genetic assimilation, a realistic co-evolutionary mechanism for cognitive abilities emerges (Depew, 2003; Hall, 2003; Weber & Depew, 2003). C. H. Waddington's genetic assimilation, for example, would predict that some individuals in every population would be, for reasons of their individual neural development and alleles already present in the gene pool, more adept at finger-counting or using material sequences. If such a phenotype also had a reproductive advantage, then in the course of comparatively few generations a genetically determined phenotype might emerge.

We envision a two stage co-evolutionary development of the ordinal ability itself. The first stage relied on embodied resources, primarily fingers. Using fingers in one-to-one correspondence, and perhaps to track small quantities, would have relied on the most appropriate "neuronal niche"—the abilities for numerosity, spatial cognition, and finger control that reside in the IPS. Their use for millennia, along with neuronal recycling, would have established the neurofunctional association between finger movement and quantification. This limited quantifying system is now virtually pan-human, suggesting an evolutionary antiquity at least as far back as the African MSA. But finger-counting is too limited to have led to a true ordinal concept. This evolved not via embodied resources, but via an artifactual scaffold or scaffolds. The most likely candidate known from the archaeological record of the African MSA is the string of beads. Initially, the phenotypes would have developed ontogenetically via neuronal recycling. But if they had a distinct fitness advantage, the part of the neural circuitry recycled for ordinality would have evolved via co-evolutionary mechanisms into circuitry devoted to constructing ordered sequences. For ordinality to have developed through the effects of material scaffolding, neuronal recycling, and co-evolution, a material scaffold such as cultural bead use would have had to be in place over many generations, and it would have to have had a selective advantage favoring the phenotype (and associated alleles) that was most adept at learning the appropriate cultural practice.

Conclusion

The preceding analysis has drawn on both cognitive neuroscience and embodied/extended cognition to address the evolutionary development of ordinal thinking. We believe the analysis warrants two conclusions, one specific and one general.

First, a gene–artifact co-evolutionary mechanism is the most likely explanation for the human neural circuitry devoted to ordinal sequence construction. Ordinal sequences are available in the human natural world only in the guise of fingers and toes, anatomical sequences that are too limited to select for a general ordinal sequencing ability. But artifacts, especially strings of beads, have the requisite characteristics to have played a co-evolutionary role. Through neuronal recycling and gene–culture co-evolution, neural resources devoted to ordinal sequencing could have evolved rapidly. Beads are not the only possible artifacts; other possibilities include notched sticks and knotted strings. However, beads are the most likely candidate. Presumably, people would have made and used notched sticks only after an ordinal concept was in place. Beads appeared in the archaeological record of the African MSA soon after the evolution of modern brain anatomy with parietal lobe expansion (Bruner, 2003, 2004). And they appear to have been common. Regardless of their specific cultural use, stringing and manipulating beads for thousands of years provided ample opportunity for the problem-solving potential (e.g., planning via ordinal time keeping) to be realized, exploited, and become the basis of a co-evolutionary process. Eventually, ordinality was coordinated with numerosity to produce numbers, a cultural construct that revolutionized human planning and reasoning (Coolidge & Overmann, 2012; Overmann et al., 2011; Chapter 5). Thus, ordinality represents a specific example of a neurally based concept that co-evolved rapidly with material culture in support of human problem-solving.

This specific evolutionary scenario is open to falsification. Research into neuronal function could demonstrate that the ordinal sequencing ability of the human brain is not a dedicated circuit, in which case the evidence from double dissociation and synaesthesia would need to be accounted for in another way. Or, archaeological evidence could provide a better alternative than beads; notched bones in the MSA, for example.

The more general conclusion of this analysis is that gene–artifact co-evolution may have been responsible for many uniquely human cognitive abilities. Several possibilities proffered by other scholars might well fit this mechanism. Malafouris (2008), as we seen, has argued that beads may have acted as extensions of the social mind, thus scaffolding concepts of social identity. Calvin (1993) has argued that aimed throwing was the key factor in human brain evolution. Good evidence for ballistic weaponry is later than Calvin suggested (roughly contemporary with beads; see Shea & Sisk, 2010), but thrown spears could still have acted in a gene–tool co-evolutionary system to yield humankind's remarkable ability to hit moving targets. Finally, Rossano (2007) has suggested that humans employ fire to achieve joint meditative states and that this ability has a clear neurological basis.

Concluding that genes and human culture co-evolved is neither novel nor particularly insightful. Here, we have proposed a specific example of gene–culture co-evolution, one that incorporates elements of embodied and extended cognition, neuronal recycling, and gene–culture co-evolution. We suspect that the ability to organize using ordinal sequences is not the only example and that humans, especially those who lived after the evolution of modern brains, relied on this mechanism to produce many unique abilities that have had a profound impact on recent human evolution.

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Notes

1. We have asked in a number of venues for examples of natural ordinal sequences, and the only possible example offered was the light spectrum, but here the problem is not the unidimensional change, but the individuation of elements.
2. Hannah Kovach, an undergraduate at the University of Colorado, Colorado Springs, drew our attention to the neuronal recycling hypothesis.

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10

Epilogue

Models, Puddings, and the Puzzle

FREDERICK L. COOLIDGE AND THOMAS WYNN

The proof of the pudding is in the eating, or so the adage goes. How well have formal cognitive models helped us document hominin cognitive evolution? What do we understand that we did not understand before? The chapters in this volume emphasize two rather different, but not mutually exclusive, avenues to evolutionary understanding. One applies models of specific cognitive domains in the context of the standard narrative of human evolution. The second presents general models of the mind that are not tethered to the standard story.

Cognitive Components and the Standard Narrative

The most familiar way that cognitive models contribute to an understanding of hominin cognitive evolution is through accounts of the evolution of specific cognitive abilities. Four of the chapters take this as a primary task, and two others incorporate such accounts into their general arguments. These accounts enable the authors and readers to place these developments within the appropriate evolutionary timing and context, thus adding to the standard narrative of hominin evolution. The following conclusions are the editors' readings of what each of these analyses have done to enhance our understanding.

1. In Chapter 7, Hodgson documents developments in the "bottom-up" (Redies, 2015) component of visual processing, neurologically linked to the primary visual cortex and more downstream resources in the parietal and temporal lobes. In regard to timing, the earliest evidence of a significant development in these resources was the advent of handaxe manufacture, about 1.8 Ma (Lepre et al., 2011). Subsequent developments in spatial processing continued until perhaps 600 kya, at which time modern spatial thinking was in

place. There were subsequent developments in how and where these abilities were applied, but not in the abilities themselves (a conclusion corroborated by Martin-Loeches in Chapter 6). Thus, the archaeological evidence indicates that hominin visuospatial processing evolved long ago, well before the advent of *Homo sapiens*.

2. In Chapter 8, Cole makes a strong case for the evolution of hominin theory of mind by identifying orders of intentionality. He places the earliest firm evidence for second-order intentionality with the first handaxe makers (an assessment similar to that of Shipton, 2010), with third-order intentionality emerging roughly 600 kya, as evidenced by giant handaxes and other exaggerated forms. Fourth- and fifth-order intentionality emerged very late via the resources of ornamentation and artifact styles, arguably after the appearance of anatomically modern humans. Thus, the need for more powerful abilities to conceive of social space and social connections within that space was a recurring theme in hominin cognitive evolution.
3. In Chapter 3, Wynn, Haidle, Lombard, and Coolidge describe evolutionary developments in expert cognition. They note that expertise evolved through enhancement of resources already in place in anthropoid object manipulation and characterize the first stone tools as apelike in regard to expertise. They then describe significant developments associated with core management strategies, circa 500 kya and symbiotic technologies after 100 kya through incorporation of autonoetic thinking and enhanced working memory capacity.
4. In Chapter 5, Overmann documents a very late cognitive development—the ability to conceive of and use an abstract number concept, a conclusion reinforced by Wynn, Overmann, Coolidge, and Janulis in Chapter 9. This significant development occurred long after the appearance of modern brains and yet, in retrospect, was as significant for modern human success as visuospatial reasoning, theory of mind, and expertise.

Each of these specific accounts presents its own evolutionary sequence, identifying different times of significant development. Thus, the overall pattern of hominin cognitive evolution was a mosaic, at least as presented by the few chapters in this volume. Part of this apparent mosaic results from imprecision in the archaeological record (e.g., the timing of third-order intentionality sometime after 1 Ma but before 500 kya), but it also reflects, we aver, the complexity of cognitive evolution. The mind did not evolve as a single general-purpose problem-solver.

But even in the face of this variegated picture, a few generalizations have begun to emerge:

A. The advent of *Homo erectus* and handaxe technology appears to have marked a crucial episode in hominin cognitive evolution, perhaps even the most significant on record.

B. A slightly less dramatic set of developments emerged roughly 600 kya.
C. Important cognitive abilities emerged well after the appearance of modern brains some 200 kya.
D. Archaeological evidence for cognitive developments does not match up very well with the paleoneurological record. True, there are important points where they do (advent of *Homo erectus*), but there are points where they do not. The "habiline" archaeological record of early stone tools appears very apelike, despite the evidence for contemporary encephalization. Much later, the final encephalization of *Homo sapiens* (not to mention Neandertals) was accompanied by no clear cognitive developments. One can sidestep this issue by appealing to the vagaries of the paleoanthropological record or the initial slowness of the ratchet effect, but students of cognitive evolution must also face the reality that brains have always been just part of the story of hominin cognitive evolution.

General Models of Cognitive Function

The analyses just reviewed focus on circumscribed cognitive domains and tether their results to the standard paleoanthropological narrative. A more ambitious approach is to develop a model of general cognitive functioning that provides insights without recourse to the standard story. This volume includes two such models, Barnard, Davidson, and Byrne's model of cognitive architectures (henceforth "architecture") and Malafouris's material engagement theory (henceforth MET).

"Architecture" is an information processing model that focuses on "how changes in information states occur in the mind" (Chapter 3 p. 4). It proposes a sequence of successively more powerful mental architectures that enabled increasing specialization, abstraction, and the ability to monitor and control more than one thing at a time. There has, of course, been a long history of information-oriented accounts of cognitive and brain evolution, arguably because information processing is the one thing that even the simplest neural networks clearly do. "Architecture's" model relies on its own internal logic and does not stand or fall on its articulation with the paleoanthropological record. That said, it can certainly provide insights relevant to archaeological puzzles. For example, by assigning *Homo erectus* to a "seven-subsystem" mental architecture, it helps us understand why there is no evidence for abstraction of any sort found in the *H. erectus* record. The utility of this model has also been demonstrated by Wadley when she explained the cognitive implications of 60,000-year-old compound glues (they required resources of a modern nine-subsystem architecture; Wadley, Hodgskiss, & Grant, 2009).

Malafouris's MET is yet another kind of cognitive model, one that challenges the very ontological status of mind itself. Most cognitive science continues to rely on a Cartesian understanding of mind in which cognition consists of internal representations and/or computations that take place in the brain. However, much research in the past 20 years has demonstrated that this "central processor" view of the mind is simply incorrect and that "peripheral resources" such as bodies and artifacts are active participants in cognition. MET builds on this fundamental realization to argue that artifacts were constituents of prehistoric thought, a shift in perspective that has profound implications for evolutionary cognitive archaeology (ECA). The artifacts we find do not just reflect cognitive abilities; they were components of cognition. Thus, in principle, it is unnecessary to construct models of internal states; components of cognition are directly accessible to archaeological inquiry. In Chapter 4, Malafouris does not expand on his earlier contributions to the Palaeolithic mind (Malafouris, 2008, 2013), but other authors in the volume do apply the embodied perspective to Palaeolithic remains. Cole, for example (Chapter 8), discusses the active role that handaxes played in creating individual identity, Martín-Loeches (Chapter 6) emphasizes the role of bodies in creating the aesthetic mind, and Overmann (Chapter 5) identifies the role played by fingers and artifacts in scaffolding an abstract number concept. In all of these cases, the evolution of hominin cognition occurred via the combined resources of brains, bodies, and artifacts.

Such combined action invites consideration of co-evolutionary models of evolutionary mechanism, but only one chapter tackles the process question directly. Wynn, Overmann, Coolidge, and Janulis (Chapter 9) describe in detail how a narrowly circumscribed cognitive ability—ordinal thinking—could have evolved via neuronal recycling, a co-evolutionary mechanism that can yield significant changes in neural organization in only a few generations. It is one possible means of reconciling the divergent accounts of MET and more traditional cognitive science.

Prospects

Although interest in the evolution of cognition has finally attained grudging, if not enthusiastic, acceptance among students of human evolution, evolutionary cognitive archaeologists remain relatively few. The challenge has always been methodological; cognitive science itself provides an abundance of theoretically sophisticated and experimentally grounded models of the human mind. ECA need not reinvent the wheel; there are plenty available. The challenge lies in applying these models to the Palaeolithic record. Some models, such as embodied/extended cognition (via, e.g., Malafouris's MET), have an interpretive potential that evolutionary cognitive archaeologists have only begun to tap. Other long-established models still have the potential to yield even more insights into human evolution (e.g., executive functions). But ECA is now long past the point where quasi-cognitive abilities such as "symbolism" or "planning" can stand as informative concepts. Formal cognitive models have become essential.

Forty years ago, in a now largely forgotten tome (Butzer & Isaac, 1975), Karl Butzer and Glynn Isaac used a compelling metaphor for the paleoanthropological record—an immense jigsaw puzzle that is missing almost all of its pieces. The few extant pieces float unconnected in metaphoric time and space. From these few extant pieces, students of human evolution must try to see a picture. Not surprisingly, our ability to do so is heavily influenced by the theoretical lenses we bring to the task. It is always better to acknowledge these lenses explicitly than to claim that the pieces somehow connect themselves. For ECA, cognitive models provide the lenses through which we view the puzzle. The resulting pictures are no less valid than those provided by human behavioral ecology or Darwinian archaeology. But they are often quite different, even incongruous. This is not a weakness. It is unlikely that paleoanthropologists will ever fill in enough of the pieces for the connections to be self-evident. We will always need models, and the more models we apply, the more we will see.

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INDEX