Accepted (peer-reviewed) version of article

It is authorized for self-archiving after an embargo period of 24 months.

Formatted by the author to enhance readability.

The Evolution of Working Memory

Frederick L. Coolidge, Thomas Wynn, and Karenleigh A. Overmann

Abstract: In this chapter, we suggest that a specific cognitive ability, an enhancement to working memory, was one of the key evolutionary acquisitions in human cognition, and indeed may even be the smoking gun of modernity. We demonstrate that Baddeley's central executive, a key component of his Working Memory (WM) model, is synonymous with the basic executive functions that underlie the more complex ones such as planning. We then discuss the importance of WM to the modern mind, and how WM might be reflected in the archaeological record.

Keywords: working memory, cognitive evolution

Introduction

Consider the following scenarios:

1. A modern chimpanzee pulls a plant out of the ground. She modifies the stem by removing the leaves with her fingers, and she pulverizes the end into fibers with her teeth. She then probes the simple tool into a termite mound, swishing it to antagonize the insects into biting the fibers and removing it carefully so that most of the termites are still holding on. She eats the termites off the tool, and once she has eaten her fill, she discards it.
2. About 2.5 million years ago, the hominid known today as *Homo habilis* hits one rock with another to produce sharp flakes. She discards everything but one or two of the flakes, which she then uses to butcher the remains of an antelope killed earlier by a large carnivore. Once the butchering is done, the hominid discards the flakes and carries off only the bits of carcass.
3. About 1.8 million years ago, another hominid, *Homo erectus*, strikes a rock against another while holding the idea of a shape in his mind. Through a series of skillful choices of angles and strikes, he imposes that shape to produce a handaxe (**Figure 1**). Once the handaxe is finished, he retains the handaxe, the larger flakes, and the remains of the original pieces of rock for his future use.
4. About 200,000 years ago, a *Homo sapiens neanderthalensis* (Neandertal) hafts a sharp, symmetrical stone point onto a spruce shaft to produce a spear, to be used later in the close-range killing of the large, dangerous animals that are his prey. Producing the spear is laborious, effort that will hopefully be repaid with his later success in the hunt.
5. About 100,000 years ago, a *Homo sapiens*, whose anatomy we would recognize as modernly human, makes a projectile with a stone point. When the point breaks during the hunt, she resharps it so she can continue to hunt with it, using other tools that she carries around with her just for this purpose.
6. Somewhere between 40,000 and 28,000 years ago, a *Homo sapiens sapiens*, whose behavior we would recognize as modernly human, carves a piece of mammoth ivory. He imposes on it the fantastic and highly imaginative shape of a female lion's head on a human body.

7. Just last week, another *Homo sapiens sapiens* working in an astrophysics laboratory runs a computerized analytical model to understand the gravitational influences of inhabitable planets on the stars they orbit. She enters observational data on stellar dynamics obtained by radio astronomy facility contributing to the project, which is funded by a mixture of government, industrial, and private funding.

Figure 1. Bifacially symmetrical handaxe.

With the exception of the first and possibly the second scenarios, it is unlikely—impossible, really—that another species could conceive and execute the complex planning inherent in them. Not even another of the great apes can plan to the same extent, and their neuroanatomy and cognitive capabilities bear the closest similarities to our own. Moreover, even language appears to be insufficient to account for the ability to plan and carry out these scenarios. There is something else at play: an ability to construct and carry out increasingly elaborate plans of action. It is an ability that is fundamental to human thinking and one that underpins much of our success. Neuropsychologists and cognitive scientists use the terms *executive functions* (EFs) and *working memory* (WM) to refer to the high-level abilities to manipulate information, reason and solve problems, and plan courses of action. These abilities must have evolved during the course of human evolution, as the scenarios suggest. But when? And how?

In the argument that follows, we suggest that a specific cognitive ability, an enhancement to WM (*enhanced working memory*, EWM), was one of the key evolutionary acquisitions in human cognition, and indeed may even be the smoking gun of modernity. We hope to demonstrate that Baddeley's central executive, a key component of his WM model, is

synonymous with the basic EFs that underlie the more complex ones such as planning. We then discuss the importance of WM to the modern mind, and how WM might be reflected in the archaeological record.

Baddeley's Central Executive and the Executive Functions

The functions of the central executive described by Baddeley (1993, 2000, 2001, 2002, 2007) in his WM model appear to be synonymous with the key EFs described by Miyake et al. (2000). Baddeley's *attentional control* is identical to the EF of *shifting*: Both entail the transferring of attention from one cognitive task or mental operation to another, as well as the suppression of interference or priming, especially when the stimulus is constant but the operation is new. The idea that mental representations held in WM are maintained and manipulated by the central executive invokes *updating*, the monitoring the mental representations held in WM and incorporating new information as needed on an ongoing basis. Finally, the notion that planning is the structuring of behavior based on the comparisons of actual and goal state mental representations involves *inhibition*, the intentional blocking of automatic or dominant responses or behaviors in favor of less prepotent ones. These abilities, whether labeled EFs or the central executive of WM, are what enable us to shift our attention at will, make and adjust decisions based on new environmental input, and plan and achieve increasingly complex goals, and it is their increase, both gradual (as in scenarios 2 through 5) and dramatic (as in scenario 6), that we believe gave rise to the modern human mind.

Baddeley and others (e.g., Baddeley & Logie, 1999; Miyake & Shah, 1999; Miyake et al., 2000) currently view the central executive either as a unitary system or multiple systems of varying functions including attention, active-inhibition, decision-making, planning, sequencing, temporal tagging, and the updating, maintenance, and integration of information from the two slave systems. Some brain function models have relegated WM (primarily phonological storage) to being simply a subcomponent of the various functions of prefrontal cortex. However, with a raft of new evidence from empirical studies (for a review of contemporary WM models and empirical evidence, see D'Esposito, 2007), it may be more parsimonious to view Baddeley's WM model as having subsumed the traditionally defined aspects of EF. In most current models, WM not only serves to focus attention and make decisions but also serves as the chief liaison to long-term memory systems and to language comprehension and production. Indeed, Baddeley (1993) has noted that had he approached these systems from the perspective of attention instead of memory, it might have been equally appropriate to label them 'working attention.'

Differing conclusions from various studies show the highly complex yet highly interrelated nature of WM and its EF. As previously mentioned, in a factor analytic study of EF, Miyake et al. (2000) identified three factors as fundamental to executive functioning: mental set shifting, information updating, and the inhibition of prepotent responses. Oberauer, Suss, Wilhelm, and Wittman (2003) proposed that WM could be differentiated into two facets: one, the content domains (akin to Baddeley's phonological store and the visuo-spatial sketchpad) and the other related to its cognitive functions (Baddeley's EF). Oberauer et al., in a statistical analysis of 30 WM tasks, found three meta-WM functions: simultaneous storage and processing, supervision (i.e., EFs or the central executive), and coordination of elements into structures. Of course, all factor analytic studies' outcomes are completely dependent on the initial set of variables.

Whether the central executive is a unitary or nonunitary concept we may still ask where, how, and why does it make its decisions? Miyake and Shah (1999) have proposed that the attention and decision-making qualities of the central executive may be an emergent property, that is, they arise as a function of the dynamic interplay of the multiple and interrelated systems associated with WM, including the two slave systems, the multiple long-term memory systems and their cortical and subcortical connections. Support for the decision-making nature of the central executive also comes from Frankish (1998a, 1998b) who has speculate that it is an innate predisposition of human consciousness to accept, reject, or act on propositions. He postulates a ‘super mind’ constituted by higher-order decision-making (as cited in Carruthers, 2002). These propositions are framed by language most often through inner speech or subvocalization, which are aspects of the WM component of phonological storage. We find it reasonable to assume that WM’s ability to maintain appropriate attention and to make decisions would have been favored by natural selection. Certainly, the abilities to attend to relevant stimuli, filter out irrelevant stimuli, inhibit prepotent responses, and t make quick and efficient decisions would have been favored over static processes. Further, it is these abilities that we believe characterize the modern human mind.

WM and the Modern Mind

The importance of WM to the modern mind can be illustrated by the curious incident of one Phineas Gage, an apparently responsible, capable, and virile 25-year-old foreman of a railroad construction crew. On September 13, 1848, he accidentally dropped a 13¼ pound iron tamping rod, over three and a half feet long and more than an inch in diameter, onto a dynamite charge, which then exploded. The iron rod was driven through the left side of the young man’s face to emerge from the top of the frontal portion of his cranium. He was taken to his nearby hotel, which was to serve as his hospital room until 32 days later, when he was able to leave his bed. At this point, the attending physician, J. M. Harlow, noted that his patient was eating and sleeping well, and that his long-term memories appeared to be intact. Seventy-four days after the accident, Phineas was able to return to his home, about 30 miles away. But there were discernable differences in his behavior, not related to his health, general intelligence, or memory. The original contractors who had hired him considered the “change in his mind” so great that they refused to rehire him. Phineas told Harlow that he could not decide whether to work or to travel. There were reports that Phineas was roaming the streets, purchasing items but without his usual concern about price. About this same time, Harlow (1868) noted that Phineas’ mind seemed “childish” and that he would make plans and change them capriciously and then abandon them just as quickly. More importantly, Harlow wrote,

Previous to his injury, though untrained in the schools, he possessed a well-balanced mind, and was looked upon by those who knew him as a shrewd, smart business man, very energetic and persistent in executing all his plans of operation. In this regard his mind was so radically changed, so decidedly that his friends and acquaintances said he was ‘no longer Gage’. (Harlow, 1868, p. 340)

In the literature, the quote “no longer Gage” has famously become associated with Phineas’ personality changes: his postmorbidity use of profanity, his depression, his irritability and capriciousness. But this, however, misses what may be the most important point: Harlow associated his patient’s most important change to the loss of the abilities that had once made him so valuable as a foreman: his once-shrewd business acumen and his former ability in “executing all of his plans of operation.” Significantly, Harlow’s description shows just how important to

the modern human mind the EFs or central executive of WM are: Without them, it would be impossible to make decisions, form goals, plan, organize, devise strategies for attaining goals, and change and devise new strategies when the initial plans fail. Simply, without them modern human success would not be possible.

The Russian neuropsychologist Luria (1966) was the first to write extensively about the EFs, noting that in patients with frontal lobe damage, the abilities for speech, motor movements, and sensations are frequently intact, yet their complex psychological activities are tremendously impaired. Significantly, he observed that they were often unable to carry out complex, purposive, and goal-directed actions. Furthermore, he found that they could not accurately evaluate the success or failure of their behaviors, especially in terms of using the information to change their future behavior. Luria found these patients unconcerned with their failures, hesitant, indecisive, and indifferent to the loss of their critical awareness of their own behaviors. Lezak (1982), a contemporary American neuropsychologist, wrote that the EFs of the frontal lobes were:

... the heart of all socially useful, personally enhancing, constructive, and creative abilities.... Impairment or loss of these functions compromises a person's capacity to maintain an independent, constructively self-serving, and socially productive life no matter how well he can see and hear, walk and talk, and perform tests. (Lezak, 1982, p. 281)

In 2001, we proposed a hypothesis in which the evolution of the EFs was a key element in the evolution of modern human behavior and culture; we subsequently expanded this hypothesis by subsuming EFs under Baddeley's concept of WM (Coolidge & Wynn, 2001, 2005). We suggest that an enhancement of WM capacity (which we have labeled EWM) occurred in the relatively recent human past, most likely somewhere around the first appearance of the anatomically modern humans depicted in scenario 5, and that this development was the final piece—a final quantum leap in cognitive evolution, if you will—in the evolution of human executive reasoning ability, language, and culture.

WM/EWM in the Archaeological Record: Methodological Considerations

What might WM—and EWM, for that matter—look like in the archaeological record? And how might we tell, methodologically speaking? In general, we shall start by examining a candidate capability from the perspective of cognitive science. We will then identify archaeologically visible sequelae, specific actions or sets of actions that are enabled by the ability in question. Since the archaeological record consists of traces of action rather than direct traces of minds, the link between action and cognition must be explicit. Finally, we will define a set of criteria (attributes) by which these actions can be reliably identified in the archaeological record. These steps will make it possible to apply different standards of evaluation to the evidence.

The strict standard, which is the only one with real persuasive power, has the following two components:

1. **Cognitive validity:** The evidence must actually require the abilities attributed to it. The cognitive ability must be one recognized or defined by cognitive science; it must be required for the actions cited; and the archaeological traces must require those actions. A strict standard of parsimony must apply. If the archaeological traces could have been generated by simpler actions, or simpler cognition, then the simpler explanation must be favored.

2. **Archaeological validity:** The archaeological evidence must itself be credible. The traces in question must be reliably identified and placed appropriately in time and space.

Admittedly, archaeological validity is complicated, not merely by the indirect nature of cognitive traces or the challenge of formulating criteria for recognizing those traces in material remains. The archaeological record itself is an enormous jigsaw puzzle, consisting of bits and pieces that must be organized, interpreted, and interrelated to each other when many of them are missing and the few that are found may not easily cohere. What gets preserved is a matter of an unlikely combination of events that only starts with deposition. Until it is found (an unlikely event in itself), artifacts and features must successfully transition through a smorgasbord of human-initiated, animal-caused, or geological displacement processes that complicate interpretation (Villa, 1982). A demonstration of the latter is seen in the recent reinterpretation of the Châtelperron site at Grotte du Renne, central France (Gravina, Mellars, & Ramsey, 2005; Mellars, Gravina, & Ramsey, 2007), in which the reattribution of artifacts from Neandertals to modern humans “effectively collapsed” the evidentiary support for Neandertal symbolic behavior (Mellars, 2010, p. 20148).

For the first step in the present analysis, we note that our cognitive candidate, WM, is the well-defined, voluminously documented component of the modern mind. Moreover, it is an ability that is highly heritable (perhaps as high as 77 percent; see Coolidge et al., 2000; also see Ando, Ono, & Wright, 2001; Hansell et al., 2001; Rijdsdijk, Vernon, & Boomsma, 2002), and it is possessed by nonhuman primates at a comparatively reduced capacity, as reflected by the differences in human and nonhuman tool use (De la Torre, 2010). As we suggested with scenarios 1 and 2, the WM of our hominid ancestors appears to have differed little, either qualitatively or quantitatively, from that of modern apes. Hints at increasing capacity (that is, capacity beyond a modern ape’s range) can be identified as far back as *Homo erectus* (1.8 million years ago), though unambiguous evidence of ubiquitous modern WM capacity might not emerge until as recently as 15,000 years ago (Wynn & Coolidge, 2009).

The second step in the present analysis is to identify activities that require not just WM, but EWM. This presents two related practical problems. First, WM capacity is typically measured in terms of numbers of discrete items (e.g., terminal words in a series of read sentences). We cannot apply such tests in prehistory, and thus a simple quantitative measure is unavailable. We must rely on behavioral correlates of WM capacity. Second, psychological tests of WM capacity rarely include activities that would leave an archaeological signature; it is necessary for the archaeologist to select the appropriate activities. In practice this requires that we, as researchers, make ordinal comparisons of everyday tasks. Because these judgments are ordinal (e.g., more versus less), they are by nature not fine-grained. For example, we will argue that planning months and years in advance is a feature of modern executive thinking enabled by modern WM. It is fairly easy to cite modern examples. But what would constitute archaic WM? We can argue that prehistoric groups who did not demonstrate appropriate activities did not have modern WM, but it is effectively impossible to assign a number. Moreover, there is always the danger of under assessing WM if we rely on only a few kinds of activities. We must therefore use a variety of different activities if we wish to have reasonable confidence in our assessment. Below we will identify technological activities, subsistence activities, and information processing activities that we suggest are reliable indicators of EWM.

The final step in the analysis is to scour the archaeological record for the earliest credible evidence for the activity in question. There are several inherent pitfalls in this step. One is the

problem of equifinality, the idea that any given end state can be reached by a variety of potential means. A second is simple serendipity. Much of the evidence we seek requires good preservation—a rarity in Palaeolithic sites—but we also need the good fortune to find such sites. Archaeologists have little control over these factors. However, we need not kowtow to the dictum “absence of evidence is not evidence of absence.” Often absence of evidence is evidence of absence. Nevertheless, it is always dangerous to conclude that evidence from one site will always be the oldest, or to adhere to too strict a chronology. As a corollary, it is important to use as many different kinds of archaeological evidence as possible. If the archaeological evidence for many different activities all point to the same chronological conclusion, then confidence in the conclusion improves. Finally, some archaeological evidence is direct—archeologists find physical remains of the activity. But some is indirect; the archaeological remains strongly imply the presence of the activity. For example, archaeologists have occasionally found actual traps made of wood and fiber. As you might suppose, these are very rare because the constituent materials rarely survive the ravages of time. The oldest such examples are only about 8,000 years old. So, was the first use of traps only 8,000 years old? Archaeologists think not, but the evidence is indirect, primarily in the form of animals that could not be effectively killed or captured without the use of traps. This indirect evidence pushes traps back to perhaps 70,000 years ago (Wadley, 2010), a considerable difference.

Evidence of WM/EWM in Technology

The irony for archaeologists is that technology is the most visible activity in the archaeological record, but one of the least likely to require the resources of EWM or even WM. Most tool making and tool use relies, often exclusively, on a style of thinking known as expertise or expert performance (Ericsson & Delaney, 1999, Keller & Keller, 1996; Wynn & Coolidge, 2004). This kind of thinking relies on procedural cognition and long-term memory—motor action patterns learned over years of practice and/or apprenticeship. It is also largely nonverbal. Very little of the problem solving ability of EWM is ever devoted to tool use. Instead, flexibility in tool use comes from the large range of procedures and solutions learned over years. The millions of stone tools produced over human evolution tell us mostly about this other cognitive system, not WM. It is not that WM was never used, just that it is almost impossible to eliminate procedural cognition as a candidate for the cognition behind the tool or use in question (e.g., equifinality and parsimony). Nevertheless, there are technical systems that do require EWM, and which cannot be reduced to procedural cognition. Most of the good examples (e.g., alloyed metals and kiln fired ceramics) appeared so late in human evolution as to engender little controversy or interest (ca. 6,000 years ago). There are just a few that extend much further back.

The further possible enhancement of WM appears to have been marked by several types of technological development, including traps and snares, reliable and maintainable technologies, and hafting.

Traps and snares. “Facility” is an archaeological term for relatively permanent immobile constructions built onto or into the landscape (Oswalt, 1976). Perhaps the most common facilities used by hunters and gatherers are traps and snares, which are facilities designed to capture or kill animals (including fish; an example is the fishing weir in **Figure 2**). Facilities, including traps and snares, are often multicomponent gadgets, occasionally very heavy, that are time-consuming to build, and which operate remotely, occasionally in the absence of direct

human engagement. It is the remote action that implicates EFs and EWM. To make a trap one must project present action toward a future, uncertain result. This requires the long range planning in space and time of modern EFs, and relies significantly on the response inhibition of the central executive of WM (delayed gratification).

Figure 2. Fishing with a stone weir. Reproduced from original paintings and drawings by Monte Crews and Kenneth Phillips in the collection of the New Jersey State Museum.

Direct archaeological evidence for traps and snares, as mentioned above, have a relatively shallow antiquity. Actual wooden fish traps date back 4,500 years in North America, and a few thousand years earlier in Europe, that is, not much earlier than the alloyed metals passed over above. The oldest direct evidence of a kind of trap appears to be the “desert kites” of the Middle East (Moore, Hillman, & Legge, 2000). These are lines of piled stone cairns, often hundreds of meters long, converging on a stone enclosure. There were used to hunt gazelle, and the oldest are about 12,000 years old.

Indirect evidence pushes traps and snares back to about 35,000 and perhaps seven 75,000 years ago. At Niah cave on Borneo, Barker et al. (2007) have evidence of extensive remains of bush pigs by about 35,000 years ago, an animal best hunted using nets or snares. Similarly, Wadley (2010) has recently argued that extensive blue duiker remains at Sibudu are indirect evidence for using traps by 75,000-year-old Middle Stone Age people in South Africa. In sum, traps and snares supply direct evidence for modern WM back to 12,000 years ago, and indirect evidence back to 75,000 years ago.

Reliable weapons. Twenty-five years ago, Bleed (1986) introduced a distinction in technical systems that has important cognitive implications, that between “maintainable” and “reliable” weapons. The former require comparatively less effort to produce but are easier to fix (“maintain”) when necessary, for example, when damaged through use. Most stone tools, even from recent time periods, qualify as maintainable. Reliable weapons, on the other hand, are designed to assure function, that is, to reduce as far as possible the chances for failure. As such they tend to be over designed, complex in the sense of having several interrelated parts, hard to maintain, and often heavy. They often require long periods of “downtime” for their construction and maintenance, and are most often intended to be deployed over short time spans of heavy use. Bleed developed this distinction as a way to understand the difference between simple stone tipped thrusting spears and the sophisticated projectile systems of North American Paleoindians, which included spear throwers, flexible aerodynamic shafts, replaceable foreshafts, and thin, fluted stone points. However, the distinction between maintainable and reliable applies generally to all technologies, not just weapons. The guiding principle behind reliable systems is that the investment of time and labor well in advance of need will maximize future success. More recently, Shea and Sisk (2010) have taken a related but narrower focus and argued that the use of complex projectile weaponry (spear throwers and bows and arrows) is a good marker of modern technical prowess. “We use the term ‘complex projectile technology’ to refer to weapons systems that use energy stored exosomatically to propel relatively low mass projectiles at delivery speeds that are high enough to allow their user to inflict a lethal puncture wound on a target from a ‘safe’ distance” (p. 102). They consider this development significant enough to qualify as a derived feature of modern behavior.

The archaeological record in North America clearly places reliable weapons back to Paleoindian times, at least 11,500 years ago (roughly the same age as the earliest desert kites in the Near East, which were also reliable technical systems). Earlier examples rest on our ability to judge time investment and effectiveness of technical systems. Following Pike-Tay and Bricker (1993), we believe that one earlier type of Palaeolithic artifact qualifies as being a component of a reliable system, and certainly an element of complex projectile technology—the bone and antler projectile points (a.k.a. sagaies) of the European Upper Palaeolithic. To make these artifacts, artisans used stone tools to remove appropriately sized blanks from a piece of bone or antler, often after soaking the raw material, and then carved the blanks into specific shapes (split based, barbed, etc.). Most were spear points hafted directly onto shafts, but others were harpoon heads, designed to come off the shaft while attached to a line. There are many examples of reworked points, attesting to the time required to make one from scratch. The most spectacular examples of such projectile points, which include the harpoons, date from the Late Upper Palaeolithic, about 14,000–18,000 years ago, with slightly simpler systems extending back to 30,000 years ago. In Africa, bone points date back even earlier, perhaps as early as 90,000 years ago in the Congolese site of Katanda (Shea & Sisk, 2010; Yellen, Brooks, Cornelissen, Mehlman, & Stewart, 1995). The European evidence is more compelling because of the contemporary evidence for managed foraging, and evidence for spear throwers and harpoons, which imply systems of gear. As yet the early African evidence consists of just the bone points, but it is provocative nonetheless.

Hafting. Hafting—attaching a stone tool to a shaft—has itself often been touted as a technological and even cognitive watershed in human evolution (Ambrose, 2001, 2010). Hafted tools represent the first time Palaeolithic people united separate elements into a single tool (**Figure 3**). These compound tools consist of three distinct elements: the stone tool (usually a spear point), the shaft, and the haft itself. It was the haft that was the challenge because it had to withstand

significant impact forces when the tool was used. Spears with hafted stone points represent a clear escalation in the human-prey arms race, and it is fair to emphasize their importance in technological history. But their cognitive significance is harder to assess. Much hinges on how the hafting was done. A simple haft using a naturally available glue has different implications than a haft requiring days of soaking animal tendons followed by controlled, heated drying of the lashings on the shaft. The former is straightforward, single-sitting task, while the latter is a multiday procedure. In a sense, the former leans towards maintainable, the latter toward reliable in the maintainable-reliable continuum. It is only the latter that carries clear implications for EWM capacity. Hafting also calls out for a discussion of invention, the conscious design of an innovative technology. Someone had to design the first haft; it could not have occurred by accident. And it would be very informative, from a cognitive perspective, to know just how that person came up with the idea. The frustrating answer is that we just do not know. We can speculate, but our speculations cannot then be used as data for a cognitive interpretation.

Figure 3. Hafted point.

The earliest evidence for hafting extends back probably 200,000 years in Europe, the Middle East, and Africa (Rots & Van Peer, 2006; Shea, Fleagle, & Assefa, 2007; Villa, Boscato, Ranaldo, & Ronchitelli, 2009; Mazza et al., 2006), and includes examples by Neandertals and modern humans. Thus far, at least, these early hafts seem to be of the simpler, single-sitting task variety, though certainly collection of natural adhesives adds a component of complexity to the task, and Grünberg (2002) and Koller, Baumer, and Mania (2001) have argued that the production of birch pitch required sophisticated knowledge of heating temperatures. It was only after 100,000 years ago that there is evidence for multiday hafting procedures. The best evidence comes from Sibudu in S. Africa (the same site as the indirect evidence hunting blue duikers with snares) at about 70,000 years ago. Here hunters used a mixture of acacia gum, a little beeswax, and powdered ochre to produce an adhesive that had to be carefully dried using fire (Wadley, Hodgskiss, & Grant, 2009). Although in theory such hafting could be accomplished by procedural cognition, the variety of constituents required for the adhesives, and the multiday procedure itself, imply the use of modern WM, particularly the EFs of projecting future action, anticipating problems, response inhibition, and contingency planning (Wadley, 2010).

Interestingly, however, Wadley argues that despite the steps in making compound adhesives for hafting (for example, abstraction, recursion, and cognitive fluidity), she notes that it does not necessarily imply the use of symbolic behavior, that is, our concept of EWM.

To summarize, three lines of technical evidence are in broad agreement. Convincing archaeological evidence extends easily back to 18,000 years ago or so, but there are strong examples going back as far as 70,000 years ago in Africa. Earlier than that there is only the single example of simple hafts, which cannot alone bear the weight of assigning modern WM or EWM. It is important to reiterate that technology is not a domain of activity that easily documents WM capacity. Procedural cognition can be effective and flexible, and can encompass almost all technical activity. Certainly hafting, or even complex projectile technology, could not alone stand as evidence for fully modern EFs. Of the examples we cite, the only one that might stand alone as an argument for modern cognition is the example of traps.

Evidence of WM/EWM in Foraging and Labor Systems

Technical evidence works better when it supports or corroborates evidence from other domains, and next to technology, the domain of activity most visible in the archeological record is subsistence—acquiring and processing food. And like technology, archaeologists' arguments for modern subsistence systems have been heavily distorted by the record of the European Upper Palaeolithic, especially its later phases, which included examples of specialized hunting of single species such as reindeer or mammoth. These were no doubt impressive subsistence systems but specialization per se does not actually require the planning resources of modern EFs and EWM. It can easily be organized and executed by expert procedural cognition. In fact this is arguably a more appropriate cognitive strategy because it consists of well-learned, automatic responses that can be selected and deployed quickly in dangerous situations. Neandertals were very good at this kind of thinking and, no surprise, we have extensive evidence for their specialized hunting (Callow & Cornford, 1986; Gaudzinski & Roebroeks, 2000). Thus, it is necessary to eschew this war-horse of modernity and identify subsistence activities that actually do require modern EFs and EWM.

Modern people manage their food supply. This is obvious in agricultural economies, where activities must be planned on a yearly scale (for nontropical systems). It clearly relies on the long-range planning of EFs and, more specifically, the response inhibition that is a key component of modern WM (e.g., retaining a portion of the harvest for replanting even in the presence of extreme want). But agriculture is not the only form of managed foraging. Most of the hunting and gathering systems archaeologists have recognized as “complex” also qualify (Price & Brown, 1985). Good recent ethnographic examples include foragers of the Northwest Coast of America, the Arctic, and Australia. In Northern and Western Australia, hunter-gatherers systematically burn tracts of land in order to encourage a second green-up of grass, which attracts herbivores. They rotate the tract to be burned every year, and do not return to a tract for at least a decade (Lewis, 1982). This is a managed system, with planning over long periods, as well as response inhibition.

Another component of modern hunting and gathering systems is a marked division of labor by age and gender (Kuhn & Stiner, 2006). Kuhn and Stiner have proposed that the division of economic labor by age and gender is a salient feature of the recent human condition and that it emerged relatively late in human evolutionary history. We note that complimentary economic roles and food sharing implies the ability to negotiate these roles and to penalize those who deviate from these norms. We note that gendered division of labor requires coordination of separate labor pools, but more importantly is manifested in the tropics by increased reliance on small, seasonal resources (plants and small animals) that require scheduled harvesting, typically

by women and children. We believe that the functions of organization, delegation, disputation resolution, and so on weakly implicate WM and its EFs.

Archaeological evidence for agriculture extends back to 10,000 years on several continents, and evidence for managed forms of hunting and gathering back another several thousand years in the guise of late Palaeolithic cultures all over the world. An especially good example is that of the Epipalaeolithic site of Abu Hureyrain Syria (Moore, Hillman, & Legge, 2000). Here a group of hunters and gatherers established a sedentary community based on hunting gazelle and gathering a wide variety of local plants. When the local conditions became much drier 11,000–10,000 years ago these people did not simply shift the focus of their hunting and gathering; they changed its very basis by beginning to cultivate rye. The interesting point is not so much the broad spectrum hunting and gathering but the inventive response to changing conditions. These people were clearly using the planning abilities enabled by EWM.

Finding evidence for managed foraging that is earlier than about 10,000 years ago is fraught with problems, mostly linked to preservation, but also to mobility patterns of earlier hunter-gatherers who rarely settled in permanent sites like Abu Hureyra. The amount of refuse is much less, and harder to characterize. Nevertheless, there are several provocative earlier examples. A well-known example is that of late Upper Palaeolithic reindeer hunters (Straus, 1996) of southwestern Europe (ca. 18,000 years ago). Here it is not the specialization that is telling (see above), but the evidence for a tightly scheduled hunting system in which herds were intercepted and slaughtered in the Fall at specific locations during migrations, but at other times of the year were hunted individually using a different set of tactics. Though other resources were used, reindeer were the clear focus year-round, using a seasonally adjusted strategy that included periods of down-time during which the hunters made and maintained their complex technical gear (see above). At about the same time, hunters on the Russian Plain used a system in which they killed large numbers of animals during late summer/early fall and then cached large quantities of meat in underground storage pits for freezing and future consumption (Soffer, 1989). Storage and delayed consumption are strong evidence for modern WM, without necessarily invoking symbolic behavior or EWM.

Earlier evidence is largely indirect. At Niah Cave on the island of Borneo (Barker et al., 2007), archaeologists have recovered large quantities of pollen from plants that flourish on recently burned areas. The local tropical conditions are quite wet, and the pollen far exceeds what one would normally expect to find, suggesting extensive human-induced burning. This evidence dates to sometime between 42,000 and 28,000 years ago. Earlier still is the evidence for hunting blue duiker in South Africa using snares or traps (70,000 years ago). Of similar antiquity is evidence from other South African sites for extensive use of corms (fleshy, semisubterranean stems), which are features of plants that flourish on burned landscapes, suggesting as at Niah human use of fire as an ecology altering tool (Deacon, 1993). Kuhn and Stiner (2006) argue that this broadening of the subsistence base in South Africa is an indication of division of labor by age and sex. In sum, the archaeological evidence for managed foraging parallels the evidence of technology. There is a strong signature going back 18,000 years or so, and a weaker, but still provocative, set of isolated examples going back 70,000 years.

Evidence of WM/EWM in Information Processing

Thus far in our discussion we have focused primarily on the long-range planning and response inhibition components of modern EFs and EWM and have traced them archaeologically through the technological and subsistence records. We now shift focus to problem solving, another of the EFs enhanced through an increase in WM capacity. WM is the active problem solving “space” of the modern mind. We use WM to construct analogies, perform thought experiments, make contingency plans, and even make metaphors. It is how and where we bring things together in thought; however, even modern WM has a limited capacity, because the episodic buffer is a limited capacity store. If the capacity of this store is depleted by holding raw information, little comparison and processing can also occur (try multiplying two four-digit numbers in your head). One solution to the problem that modern humans regularly use is externalization of some of this information, that is, holding the information outside of the mind itself. This is an aspect of extended cognition, which has recently received significant attention in cognitive science (Wilson & Clark, 2009), and even archaeology (Malafouris, 2008, 2010). Our interest is on the implications that extended cognition holds for WM, and the primary effect is to extend WM capacity by relieving the necessity to hold information in the episodic buffer, thereby freeing capacity for the processing components of the central executive. Examples of such externalized storage systems abound in the modern world—writing, numbers, calculators, and so on. External systems need not be artifactual—one can, for example, count on one’s fingers—but they often are artifactual, which gives us an avenue to follow into the prehistoric past.

Figure 4. (a) Tai counting device, ca. 14,000 (left);
(b) Abri Blanchard lunar calendar, ca. 28,000 (right).

It is uncontroversial to assert that early writing and accounting systems, which date back at least 5,000 years, were external information storage. Systems of clay tokens, used for accounting purposes, extend the record back several thousand years into the early Neolithic (Malafouris, 2010; Schmandt-Besserat, 1992). We pick up the trail about 12,000 years ago at the site of Grotte du Tai in western France (Marshack, 1991b). The plaque (**Figure 4a**) appears to have been a record keeping device. Someone engraved a series of long lines crossed by groups of slashes on a piece of flat bone. Marshack, and later d’Errico (2001), examined the markings microscopically and determined that they were produced by different tools, probably in different episodes. Marshack argued that the marks were produced by different techniques that corresponded to lunar phases, while d’Errico concluded simply that it was an external memory

device. We do not know what the engraver was tracking, but it was clearly something, attesting to a desire to externalize information, thereby freeing up WM capacity for processing. Similar objects, some more elaborate and others not as much so, date back in Europe to about 28,000 years ago (d'Errico et al., 2003). An example is the Abri Blanchard plaque (**Figure 4b**). Marshack (1991a) argued that the markings were iconic representations of the different phases of the moon, and thus the device was a lunar calendar; this supposition has been supported by recent field experiments in archaeoastronomy (Jègues-Wolkiewiez, 2005). Again, the device externalized the information, enabling its possessor to use his or her WM capacity for other tasks.

Figure 5. Hohlenstein-Stadel figurine, ca. 32,000.

Earlier still and equally provocative are therianthropic figurines from Germany, the most famous of which is the Hohlenstein-Stadel figurine (**Figure 5**) referred to in scenario 6. This is an image of lion-headed person (or human-bodied lion) carved in elephant ivory, roughly 28cm high and about 32,000 years old (Hahn, 1986). It is certainly an evocative piece, and has inspired much discussion about symbolism and Upper Palaeolithic religious thinking. It also has a number of important implications for cognition (Wynn, Coolidge, & Bright, 2009), one of which concerns WM. The figurine is an externalized abstraction. Such a creature does not exist in the real world, and it may have been metaphorically glued together, initially at least, in the WM of some Upper Palaeolithic person. The problems people need to solve are not always practical issues in day-to-day life. They are also social, and even metaphysical. The Hohlenstein-Stadel figurine may be the externalization of such a metaphysical problem, and its externalized presence frees up WM of the artisan, and also observers, to ponder other related existential issues. So far, our discussion of externalized information processing has not yielded any surprises. Suggesting that Upper Palaeolithic

people in Europe 32,000 years ago exercised modern cognition is neither a novel nor a controversial conclusion. But what about earlier? Can we push externalized information back as far as the early evidence of traps, or managed foraging? The answer is yes, but it requires a slightly different take on a famous set of artifacts—the Blombos beads (**Figure 6**).

Blombos Cave is a site on the coast of South Africa whose Middle Stone Age levels date back at least 77,000 years. These MSA levels have famously yielded engraved bones, shaped and engraved pieces of ochre, bone awls, and marine shell beads (Henshilwood & Marean, 2003; Henshilwood & Dubreuil, 2009; d'Errico, Henshilwood, Vanhaeren, & van Niekerk, 2005). These are among the earliest putatively modern artifacts yet found, and make a strong case for extending many of the components of modern behavior and cognition back to this early period.

But the initial enthusiasm has recently been tempered by more sober critiques. D’Errico, Henshilwood, and colleagues (2005), for example, argued that the presence of decorative beads indicates that the inhabitants had fully syntactical language. This conclusion was then elegantly challenged by Botha (2008), who pointed out that d’Errico and Henshilwood had not made explicit and convincing bridging arguments linking beads to language. Henshilwood and Dubreuil (2009) have replied, providing part of the linkage (a very nice example of a productive scholarly exchange), but the implications of the beads are still not entirely clear. We suggest that an alternative approach is to look at these artifacts not in their possible symbolic role, but as externalized information storage. Henshilwood and Botha agree that the shells with punched holes were beads, and that the beads were worn as ornaments. But why does one wear beads? One answer is that one wears beads to send information about oneself to another person. This could be an explicit message about social status (“I am an adult,” “I am wealthy,” “I am a surfer,” and so on), or an implicit message (“I am a good mate prospect”), but by changing how others view the wearer, the wearer is externalizing information about him or herself.

Figure 6. Six of the Blombos cave beads, ca. 77,000.

Curiously, there is an alternative function for these beads that neither Henshilwood nor Botha have considered. They might have been tally devices, used to keep track of (remember) some sequential phenomena (much like modern rosary beads). The social implications of this option are different from the decorative bead interpretation, but the information implications are similar: Beads were an externalized store of information, freeing WM to devote space in the episodic buffer for processing information, rather than just holding it in attention.

This evidence of externalized information storage is provocative. We live in a modern world where externalized information has come to dominate, perhaps even overwhelm, our daily lives, and the thought that it had its roots far back in the stone age is certainly provocative. However, for our topic at hand—WM and EWM—external storage of information is actually an ambiguous signature. Externalization of information would release storage space for episodic buffers of *whatever capacity*, not just modern capacity. There need only be enough capacity to hold the external device as a token of some kind in the episodic buffer as one performs processes upon it. Because of this ambiguity, we suggest that evidence for the use of external storage devices cannot, on its own, provide compelling evidence for modern EWM, but perhaps they do argue for lower-level abstractive processes (that is, the maintenance and manipulation of mental representations with some kind of internal concept or referent) at the very least. It can, however, stand as corroborating evidence for assessments established by other means. As such, it supports the picture painted using technology and subsistence, that is, strong evidence in this case going back to perhaps 30,000 years, and weaker evidence extending further to 77,000 years ago.

Conclusion and Discussion

When we apply the strict standard to the EFs and their archaeological presence, the following picture emerges:

The ad hoc tool behavior seen in scenario 2, in which *Homo habilis* created, used, and discarded a stone tool about 2.5 million years ago, does not appear to differ greatly from that of modern apes. As suggested by scenario 1, in which a modern chimpanzee created an ad hoc tool for termite fishing, modern apes do not carry their tools around for future use; they discard them once they are done using them. However, the behavioral changes in scenario 3, in which *Homo erectus* created a handaxe about 1.8 million years ago, point to the development of important cognitive changes. The hominids in scenario 3 have begun to carry tools and tool materials around with them; we know this because both tools and tool material are found at great distances from the origins of the materials. A concurrent change in the archaeological record that signals a possible change in WM is the bifacial symmetry being imposed on handaxes (**Figure 1**), suggesting an emerging ability to hold mental representations in mind—in WM, that is. These changes in the archaeological record suggest that some improvement in WM has occurred, even if only a gradual increase in capacity concomitant with the increasing hominid brain volume that is also taking place.

In scenario 4, a Neandertal produced a maintainable tool (a spear with a hafted point, **Figure 3**) about 200,000 years ago, and in scenario 5, a *Homo sapiens* produced a reliable tool (a projectile with a stone point) about 100,000 years ago. Maintainable and reliable tools are further archaeological indications of behavioral change pointing to cognitive change. The shift from ad hoc technologies to maintainable and reliable ones suggests that the hominids have acquired an increased awareness of time in the sense of episodic memory (Coolidge & Wynn, 2008; Tulving, 2002), as well as increased abilities for imagining contingencies, planning, and response inhibition. Reliable weapons, and in particular complex projectile weapons, rely on the EF ability to plan over long stretches of time, and especially the response inhibition of WM (i.e., do not hunt today, even if you are hungry, but instead invest your effort in producing tools more likely to succeed tomorrow), and contingency planning (if the foreshaft breaks, slip in a new one; it is quicker than making an entire spear). These changes in the archaeological record imply that a gradual but substantial improvement in WM has occurred, perhaps in WM capacity, the types of information accessible and manipulable by WM, or both.

In scenario 6, a *Homo sapiens sapiens* carved a piece of ivory into a fantastic shape approximately 40,000 to 28,000 years ago, and in doing so provides us with evidence of behavior that points to a quite dramatic change in cognition. The Hohlenstein-Stadel figurine (**Figure 5**) suggests modern cognitive abilities of abstraction, cross-domain thinking (i.e., metaphor), and the ability to externalize a mental representation in a way that frees up WM for additional processing. The sophistication of this artifact, we suggest, implies EWM, a WM ability that resembles our own in its capacity and the information domains available for its manipulation. In many ways it also greatly resembles scenario 7, the present-day astrophysics example, in which things like technology and social organizations have expanded in complexity and scale, though modern WM remains on par with that seen in scenario 6.

The figurine and other archaeological evidence (technology, subsistence, and information processing devices) all suggest a relatively late emergence of modern EFs. Most of the evidence postdates 25,000 years ago, and it is not until 15,000 years ago that EFs appear to have been both unambiguous and ubiquitous.

There are four ways in which scholars could interpret this result:

1. Reject it entirely. Absence of evidence is not evidence of absence, or so the adage goes. The taphonomic threshold (Bednarik, 1994) and the serendipity of archaeological discovery have yielded a misleading signature. Moreover, the strict standard is too strict, and places unreasonable demands on archaeological inference.
2. This is the expected signature of the ratchet effect of culture change. EFs evolved long before 30,000 years ago and enabled modern innovation and culture change, but it required millennia before these changes accumulated to the point of archaeological visibility.
3. The mutation enabling EWM occurred long before 30,000 years ago but required millennia to increase in frequency to levels at which significant numbers of people expressed the EFs that are necessary for group planning (note that this interpretation is similar to #2, but here the emphasis is on biological process, not culture change).
4. The signature is accurate. EWM and EFs evolved late in a human population that was already anatomically modern. They then spread very rapidly because of their clear advantage in long-term planning, and innovative responses to challenge. Furthermore, modern empirical evidence supports the strong relationship between WM and fluid intelligence, i.e., novel problem solving.

A salient and long-known feature of the Palaeolithic record would appear to favor option #4: About 50,000 to 30,000 years ago, the pace of culture change accelerated dramatically, beyond what seems explainable as the vagaries or biases of artifactual preservation, or as responses to the late Pleistocene climatic change. Yes, there were significant climatic events associated with late Pleistocene environments, but there had been significant environmental changes many times before without such a dramatic response. The pace is also different from the gradual increases in WM that appear with *Homo erectus* about 1.8 million years ago and which characterize hominid WM for well over the next million and a half years. The veritable explosion of behavioral changes that take place between 50,000 and 30,000 years ago is consistent with the idea that a cognitive “leap” has occurred, and one that we believe is consistent with an enhancement to WM through a genetic or epigenetic event. This time, the human response to late Pleistocene challenges was facilitated by modern EFs, and the long-term consequence was, ultimately, the modern world.

References

- Ambrose, S. (2010). Evolution of composite-tool technology, constructive memory, and language: Implications for the evolution of modern human behavior. In T. Wynn & F. L. Coolidge (Eds.), *Working memory: Beyond language and symbolism* (pp. S135–S147). Chicago, IL: University of Chicago Press.
- Ambrose, S. H. (2001). Paleolithic technology and human evolution. *Science*, 291(5509), 748–753.
- Ando, J., Ono, Y., & Wright, M. J. (2001). Genetic structure of spatial and verbal working memory. *Behavior Genetics*, 31(6), 615–624.
- Baddeley, A. D. (2007). *Working memory, thought, and action*. Oxford, UK: Oxford University Press.

- Baddeley, A. D. (1993). Working memory or working attention? In A. D. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness, and control: A tribute to Donald Broadbent* (pp. 152–170). Oxford, UK: Oxford University Press.
- Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417–423.
- Baddeley, A. D. (2001). Is working memory working? *American Psychologist*, 11, 851–864.
- Baddeley, A. D. (2002). Is working memory still working? *European Psychologist*, 7(2), 85–97.
- Baddeley, A., & Logie, R. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 28–61). New York, NY: Cambridge University Press.
- Barker, G., Barton, H., Bird, M., Daly, P., Datan, I., Dykes, A. ... & Turney, C. (2007). The ‘human revolution’ in lowland tropical Southeast Asia: The antiquity and behavior of anatomically modern humans at Niah Cave (Sarawak, Borneo). *Journal of Human Evolution*, 52(3), 243–261.
- Bednarik, R. G. (1994). A taphonomy of palaeoart. *Antiquity*, 68, 68–74.
- Bleed, P. (1986). The optimal design of hunting weapons: Maintainability or reliability? *American Antiquity*, 51(4), 737–747.
- Botha, R. (2008). Prehistoric shell beads as a window on language evolution. *Language and Communication*, 28(3), 197–212.
- Callow, P., & Cornford, J. M. (1986). La Cotte de St. Brelade 1961–1978: Excavations by C. B. M. McBurney. Norwich, UK: Geo Books.
- Carruthers, P. (2002). The cognitive functions of language. *Behavioral and Brain Sciences*, 25, 657–675.
- Coolidge, F. L., & Wynn, T. (2001). Executive functions of the frontal lobes and the evolutionary ascendancy of *Homo sapiens*. *Cambridge Archaeological Journal*, 11(2), 255–260.
- Coolidge, F. L., & Wynn, T. (2005). Working memory, its executive functions, and the emergence of modern thinking. *Cambridge Archaeological Journal*, 15(1), 5–26.
- Coolidge, F. L., & Wynn, T. (2008). The role of episodic memory and autonoetic thought in Upper Paleolithic life. *PaleoAnthropology*, 2008, 212–217.
- Coolidge, F. L., & Wynn, T. (2009). The rise of *Homo sapiens*: The evolution of modern thinking. Chichester, UK: Wiley-Blackwell.
- Coolidge, F. L., Thede, L. L., & Young, S. E. (2000). Heritability and the comorbidity of ADHD with behavioral disorders and executive function deficits: A preliminary investigation. *Developmental Neuropsychology*, 17, 273–287.
- D’Errico, F. (2001). Memories out of mind: The archaeology of the oldest memory systems. In A. Nowell (Ed.), *In the mind’s eye: Multidisciplinary approaches to the evolution of human cognition* (pp. 33–49). Ann Arbor, MI: International Monographs in Prehistory.

- D'Errico, F., Henshilwood, C., Lawson, G., Vanhaeren, M., Tillier, A.-M., Soressi, ... & Julien, M.. (2003). Archaeological evidence for the emergence of language, symbolism, and music—an alternative multidisciplinary perspective. *Journal of World Prehistory*, 17(1), 1–70.
- D'Errico, F., Henshilwood, C., Vanhaeren, M., & van Niekerk, K. (2005). *Nassarius kraussianus* shell beads from Blombos Cave: Evidence for symbolic behaviour in the Middle Stone Age. *Journal of Human Evolution*, 48(1), 3–24.
- D'Esposito, M. (2007). From cognitive to neural models of working memory. *Philosophical Transactions of the Royal Society B, Biological Sciences*, 362(1481), 761–772.
- De la Torre, I. (2010). Insights on the technical competence of the early Oldowan. In A. Nowell & I. Davidson (Eds.), *Stone tools and the evolution of human cognition* (pp. 45–65). Boulder, CO: University Press of Colorado.
- Deacon, H. (1993). Planting an idea: An archaeology of Stone Age gatherers in South Africa. *South African Archeological Journal*, 48, 86–93.
- Ericsson, K., & Delaney, P. (1999). Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 257–297). New York, NY: Cambridge University Press.
- Frankish, K. (1998a) A matter of opinion. *Philosophical Psychology*, 11, 423–442.
- Frankish, K. (1998b) Natural language and virtual belief. In P. Carruthers & J. Boucher (Eds.), *Language and thought* (pp. 248–269). Cambridge, UK: Cambridge University Press.
- Gaudzinski, S., & Roebroeks, W. (2000). Adults only: Reindeer hunting at the Middle Palaeolithic site Salzitter Lebenstedt, northern Germany. *Journal of Human Evolution*, 38(4), 497–521.
- Gravina, B., Mellars, P., & Ramsey, C. B. (2005). Radiocarbon dating of interstratified Neanderthal and early modern human occupations at the Chatelperron type-site. *Nature*, 438(3), 51–56.
- Grünberg, J. (2002). Middle Palaeolithic birch-bark pitch. *Antiquity*, 76(1), 15–16.
- Hahn, J. (1986). Kraft und aggression: Die botschaft der eiszeitkunst in Aurignacien süddeutschlands? Vol. 7. Tübingen, Germany: Archaeological Venatoria.
- Hansell, N. K., Wright, M. J., Smith, G. A., Geffen, G. M., Geffen, L. B., & Martin, N. G. (2001). Genetic influence on ERP slow wave measures of working memory. *Behavior Genetics*, 31, 603–614.
- Harlow, J. M. (1868). Recovery from the passage of an iron bar through the head. *Publications of the Massachusetts Medical Society*, 2, 327–346.
- Henshilwood, C. S., & Marean, C. W. (2003). The origin of modern human behavior: Critique of the models and their test implications. *Current Anthropology*, 44(5), 627–651.
- Henshilwood, C., & Dubreuil, B. (2009). Reading the artefacts: Gleaning language skills from the Middle Stone Age in southern Africa. In R. Botha (Ed.), *The cradle of language* (pp. 41–63). Stellenbosch, South Africa: Stellenbosch University.

- Hovers, E. (2006). Comment on 'What's a mother to do: The division of labor among Neandertals and modern humans in Eurasia'. *Current Anthropology*, 47, 965–966.
- Jègues-Wolkiewiez, C. (2005). Aux racines de l'astronomie, ou l'ordre caché d'une oeuvre paléolithique. *Antiquités Nationales*, 37, 43–62.
- Keller, C., & Keller, J. (1996). *Cognition and tool use: The blacksmith at work*. Cambridge, UK: Cambridge University Press.
- Koller, J., Baumer, U., & Mania, D. (2001). High-tech in the Middle Palaeolithic: Neandertal-manufactured pitch identified. *European Journal of Archaeology*, 4(3), 385–397.
- Kuhn, S. L., & Stiner, M. C. (2006). What's a mother to do? The division of labor among Neandertals and modern humans in Eurasia. *Current Anthropology*, 47(6), 953–980.
- Lewis, H. (1982). Fire technology & resource management in aboriginal North America and Australia. In E. Hunn (Ed.), *Resource managers: North American and Australian hunter-gatherers* (pp. 45–68). Washington, DC: American Association for the Advancement of Science.
- Lezak, M. (1982). The problem of assessing executive functions. *International Journal of Psychology*, 17, 281–297. Luria, A. R. (1966). *Higher cortical function in man*. New York, NY Basic Books.
- Malafouris, L. (2008). Beads for a plastic mind: The 'Blind Man's Stick' (BMS) hypothesis and the active nature of material culture. *Cambridge Archaeological Journal*, 18(3), 401–414.
- Malafouris, L. (2010). Grasping the concept of number: How did the sapient mind move beyond approximation? In C. Renfrew & I. Morley (Eds.), *The archaeology of measurement: Comprehending heaven, earth and time in ancient societies* (pp. 35–42). Cambridge, UK: Cambridge University Press.
- Marshack, A. (1991a). *The roots of civilization: The cognitive beginnings of man's first art, symbol and notation*. Kingston, RI: Moyer Bell Ltd.
- Marshack, A. (1991b). The Tai Plaque and calendrical notation in the Upper Palaeolithic. *Cambridge Archaeological Journal*, 1(1), 25–61.
- Mazza, P. P. A., Martini, F., Sala, B., Magi, M., Colombini, M. P., Giachi, G., ... & Ribechini, E. (2006). A new Palaeolithic discovery: Tar-hafted stone tools in a European Mid-Pleistocene bone-bearing bed. *Journal of Archaeological Science*, 33(9), 1310–1318.
- Mellars, P. (2010). Neanderthal symbolism and ornament manufacture: The bursting of a bubble? *Proceedings of the National Academy of Sciences*, 107(47), 20147–20148.
- Mellars, P., Gravina, B., & Ramsey, C. B. (2007). Confirmation of Neanderthal/modern human interstratification at the Chatelperronian type-site. *Proceedings of the National Academy of Sciences*, 104(9), 3657–3662.
- Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York, NY: Cambridge University Press.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, 41, 49–100.

- Moore, A. M. T., Hillman, G. C., & Legge, A. J. (2000). *Village on the Euphrates: From foraging to farming at Abu Hureyra*. Oxford, UK: Oxford University Press.
- Oberauer, K., Suss, H.-M., Wilhelm, O., & Wittman, W. W. (2003). The multiple faces of working memory: Storage, processing, supervision, and coordination. *Intelligence*, 31, 167–193.
- Oswalt, W. (1976). *An anthropological analysis of food-getting technology*. New York, NY: John Wiley & Sons.
- Pike-Tay, A., & Bricker, H. (1993). Hunting in the Gravettian: An examination of evidence from southwestern France. In H. Bricker, P. Mellars, & G. Peterkin (Eds.), *Hunting and animal exploitation in the Later Palaeolithic and Mesolithic of Eurasia* (pp. 127–144). Washington, DC: American Anthropological Association.
- Price, T.D., & Brown, J. A. (1985). *Prehistoric hunter-gatherers: The emergence of cultural complexity*. New York, NY: Academic Press.
- Rijsdijk, F. V., Vernon, P. A., & Boomsma, D. I. (2002). Application of hierarchical genetic models to Raven and WAIS subtests: A Dutch twin study. *Behavior Genetics*, 32(3), 199–210.
- Rots, V., & Van Peer, P. (2006). Early evidence of complexity in lithic economy: Core-axe production, hafting and use at late Middle Pleistocene site 8-B-11, Sai Island (Sudan). *Journal of Archaeological Science*, 33(3), 360–371.
- Schmandt-Besserat, D. (1992). *How writing came about*. Austin, TX: University of Texas Press.
- Shea, J., & Sisk, M. (2010). Complex projectile technology and *Homo sapiens* dispersal into Western Eurasia. *PaleoAnthropology*, 2010, 100–122.
- Shea, J., Fleagle, J., & Assefa, Z. (2007). Context & chronology of early *Homo sapiens* fossils from the Omo Kibish. In P. Mellars, K. Boyle, O. Bar-Yosef, & C. B. Stringer (Eds.), *Rethinking the human revolution* (pp. 153–164). Cambridge, UK: McDonald Institute for Archaeological Research.
- Soffer, O. (1989). Storage, sedentism and the Eurasian Palaeolithic record. *Antiquity*, 63, 719–732.
- Straus, L. G. (1996). Holocene transition in southwest Europe. In L. G. Straus, B. V. Eriksen, J. Erlandson, & D. Yesner (Eds.), *Humans at the end of the Ice Age: The archaeology of the Pleistocene-Holocene transition* (pp. 83–99). New York, NY: Plenum Press.
- Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology*, 53, 1–25.
- Villa, P. (1982). Conjoinable pieces and site formation processes. *American Antiquity*, 47(2), 276–290.
- Villa, P., Boscato, P., Rinaldo, F., & Ronchitelli, A. (2009). Stone tools for the hunt: Points with impact scars from a Middle Paleolithic site in southern Italy. *Journal of Archaeological Science*, 36(3), 850–859.
- Wadley, L. (2010). Were snares & traps used in the Middle Stone Age and does it matter? A review and a case study from Sibudu, South Africa. *Journal of Human Evolution*, 58(2), 179–192.
- Wadley, L., Hodgskiss, T., & Grant, M. (2009). Implications for complex cognition from the hafting of tools with compound adhesives in the Middle Stone Age, South Africa. *Proceedings of the National Academy of Sciences of the United States of America*, 106(24), 9590–9594.

- Wilson, R., & Clark, A. (2009). How to situate cognition: Letting nature take its course. In P. Robbins & M. Aydede (Eds.), *The Cambridge handbook of situated cognition* (pp. 55–77). Cambridge, UK: Cambridge University Press.
- Wynn, T., & Coolidge, F. L. (2004). The expert Neandertal mind. *Journal of Human Evolution*, 46(4), 467–487. Wynn, T., Coolidge, F. L., & Bright, M. (2009). Hohlenstein-Stadel and the evolution of human conceptual thought. *Cambridge Archaeological Journal*, 19(1), 73–83.
- Yellen, J. E., Brooks, A. S., Cornelissen, E., Mehlman, M. J., & Stewart, K. (1995). A Middle Stone age worked bone industry from Katanda, Upper Semliki Valley, Zaire. *Science*, 268(5210), 553–556.