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Journal of Human Evolution 46 (2004) 467–487
JHE

The expert Neandertal mind

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Received 15 September 2003; accepted 31 January 2004

Abstract

Cognitive neuropsychology, cognitive anthropology, and cognitive archaeology are combined to yield a picture of Neandertal cognition in which expert performance via long-term working memory is the centerpiece of problem solving. This component of Neandertal cognition appears to have been modern in scope. However, Neandertals' working memory capacity, which is the ability to hold a variety of information in active attention, may not have been as large as that of modern humans. This characteristic helps us understand features of the archaeological record, such as the rarity of innovation, and allows us to make empirically based speculations about Neandertal personality.

Keywords: Neandertal; Long-term working memory; Expert performance; Levallois

Introduction

This article presents an attempt to describe some of the components of Neandertal thinking, cognition, and personality. Our argument is grounded in established cognitive theory, both psychological and anthropological, and supported by direct archaeological evidence for structured Neandertal activity, the Levallois reduction strategy in particular. Our hypothesis is that Neandertals relied on a form of expert cognition known as long-term working memory, that this ability was essentially modern in scope, and that it formed the centerpiece of Neandertal problem solving. As a corollary, we further suggest that modern human problem solving arose through an enhancement of working memory that enabled innovative and experimental thinking. We will also speculate about Neandertals' personality characteristics based upon the archaeological record and studies in cognitive psychology and clinical neuropsychology.

Premises

Our characterization of the Neandertal mind rests on four premises, each of which is arguable. However, we believe that each is sufficiently established to warrant what follows.

(1) Modern humans replaced Neandertals. By this we mean simply that after the arrival of

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0047-2484/04/$ - see front matter
doi:10.1016/j.jhevol.2004.01.005

anatomically and behaviorally modern humans in Europe, sometime after 50 Ka, Neandertals disappeared as a distinct population. There remains considerable disagreement in paleoanthropology about how this replacement occurred, but there is general consensus that the replacement did occur.

(2) It appears necessary to posit a cognitive/neurological difference between Neandertals and modern humans; superiority of technology or culture cannot alone account for the success of modern humans. We derive this premise from two seemingly inconsistent features of the paleoanthropological record. First, at least in the initial stages of contact (late Mousterian and early Aurignacian), modern and Neandertal technology were not dramatically different. Both were based on stone tools, projectiles, fire, shelter, and so on; there were differences in style to be sure, but no qualitative difference in control of energy (e.g., no use of animal traction or other external power source) or efficiency of technology (we maintain, for example, that the significance of prismatic blade technology has long been overstated). Moreover, modern and Neandertal foraging were also similar—hunting and gathering, including some specialized hunting of single species (Marean and Assefa, 1999; Grayson and Delpech, 2002; Steele, 2003). Superficially, at least, the two cultures do not appear to have been radically different; they were both stone-age hunters and gatherers, certainly no more distinct from one another than the most different modern cultures. This makes the second feature of the paleoanthropological record a true puzzle: despite this overall cultural similarity, Neandertals never truly acculturated. Despite direct or indirect contact for thousands of years (Mellars, 1996), Neandertals never fully acquired the trappings of modern human culture (or vice versa). Such a pattern of coexistence for millennia without acculturation does not fit easily into anthropology's understanding of culture process. It suggests that there must have been a more fundamental difference linked to Neandertal and modern human capacities for culture, in other words, a cognitive difference. There have been many attempts to characterize this cognitive difference, mostly based on global models of the mind. More recent examples include Mithen's (Mithen, 1996) argument for lack of cognitive fluidity, Dennett's (Dennett, 1991) argument for rolling consciousness, and Donald's (Donald, 1991) argument for mythic culture.

(3) This cognitive difference cannot have been dramatic. Here we agree with Hayden:

> There may certainly have been some changes in mental capacity and composition from Neandertal to fully modern human forms (corresponding to many excavators' intuitive feeling that there is "something" intangibly different about Neandertal behavior). However, at the level of biological capacities, these appear to be very subtle; neither the relative change in brain size nor morphology indicates that this was a very significant change.… Neandertals may not have been quite capable of doing nuclear physics or calculus; however, it is a travesty of the available data to argue that they did not have the full complement of basic human faculties or act in recognizably modern fashions (Hayden, 1993: 137).

Neandertals did compete on a par with anatomically modern humans for thousands of years and may even have out-competed them for several millennia in the Levant (Arsuaga, 2001; Shea, 2003). Had they possessed a dramatically less powerful intelligence, this situation is unlikely to have occurred. Comparisons of Neandertal and modern behavior have tended either to overemphasize the differences (Binford, 1981) or overemphasize the similarities (d'Errico et al., 1998). A more appropriate solution is to posit a small cognitive difference that had profound long-term consequences.

(4) Much modern thinking is still based on abilities that evolved long ago. It is very unlikely that the advent of modern humans was marked by a total reorganization of the brain; it is probable that much of modern thinking still consists of processes that evolved in earlier times. Many modern human activities place minimal demands on problem solving ability (the overworked driving-to-work example). More likely, the neural change leading to modernity was modest and added to the abilities already possessed by premodern populations [e.g., *Homo helmei* in Africa

(McBrearty and Brooks, 2000) and Neandertals in Europe and western Asia]. If we can identify and peel away this final acquisition, we should be able to describe the Neandertal mind itself.

Methods

Because we do not have experimental access to Neandertals we must draw on several indirect methods of enquiry.

1. Cognitive neuropsychology, in particular, studies of working memory and skilled cognition. This approach is based primarily on classic controlled experimental scenarios in which the targeted activities are narrowly defined, subjects tested in controlled settings, and rigorous quantitative measures applied. The subjects in these experiments either have documented brain dysfunction or damage, or may be normal and used to establish a clear reference population. Precise physiological assessment with neuroimaging techniques, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) has recently aided greatly in the neuronal localization of many neuropsychological functions and other behaviors.
2. Cognitive anthropology, in particular, studies of the cognitive basis of technological activity. Cognitive anthropology differs from cognitive psychology in its emphasis on "real world" activities, and its use of participant observation and ethnographic description. Despite methodological differences, cognitive psychology and cognitive anthropology are not incompatible, and in fact together provide a powerful approach to understanding the human mind.
3. Cognitive archaeology, in particular the analysis of stone tool manufacture using insights derived from (1) and (2). Cognitive archaeology, as it is most successfully practiced, is a form of processual archaeology (Nowell, 2001; Wynn, 2002) that relies on cognitive theories to interpret action sequences reconstructed from the archaeological record itself and from experimental replication.

The final piece that made minds modern

In our recent work (Coolidge and Wynn, 2001; Wynn and Coolidge, 2003; Coolidge and Wynn, in press), we have proffered the following scenario as the final neuronal rearrangement that led to modern thinking. This scenario is based on Baddeley and Hitch's (1974) original concept of working memory. As conceived of by Baddeley and Hitch, and recently modified by Baddeley and Logie (1999) and Baddeley (2001), working memory is a tripartite cognitive system consisting of a central executive, primarily involved in maintaining relevant attention and decision-making (the latter two processes are part of the executive functions of the frontal lobes), and two slave systems, phonological storage or articulatory loop for the maintenance of speech-based information and the visuospatial sketchpad, an interface for visual and spatial information. We offered evidence from behavioral genetics for the highly heritable basis of the executive functions of working memory and its slave systems and hypothesized that a relatively simple mutation in this system may have produced fully modern thinking. We further postulated that this mutation was either specific to phonological storage, and resulted in a lengthened capacity to maintain speech sounds, or was more generic and resulted in an enhancement of the general capacity of the central executive. The latter might have included a greater ability to maintain attention despite competing but non-relevant stimuli. Because working memory has been empirically shown to be strongly related to both general intelligence (Kyllonen, 1996) and native, fluid intelligence (Kane and Engle, 2002), this mutation might have subsequently had a profound positive effect on the general reasoning abilities of modern humans. We have labeled this effect "enhanced working memory" (EWM). We also reviewed archaeological evidence that supports a relatively recent date for such a mutation. Even if it yielded only a slight selective advantage, such a mutation could have spread rapidly in African populations, enabling the dramatic spread of anatomically and behaviorally modern humans after 50 Ka. There are at least two possible scenarios (Wynn and Coolidge, 2003). In

Table 1
Definitions of working memory terminology

Working memory refers to Baddeley's model of cognition containing three major components: (1) a decision-making central executive, and two slaves systems; (2) the phonological loop; and (3) the visuospatial sketchpad.	
Central executive is the decision-making component of working memory, the chief functions of which are attention to task, selective inhibition, and goal-direction.	
Phonological loop consists of two components: (1) a short-term store for verbal and acoustic stimuli (hence the name "phonological store") and (2) an articulatory (vocal or subvocal) rehearsal mechanism, which allows for the transfer to long-term memory by way of the hippocampus.	
Visuospatial sketchpad is a temporary place of storage for the interface between visual and spatial information and allows for its manipulation and long-term storage. It is important for problems of spatial location and orientation.	
Long-term working memory is a long-term storage that does not fade rapidly and generally takes more trials to establish than for verbal or declarative memories. It consists of skills (which we have labeled savoir faire) or the ability to replay motor behaviors, techniques, or procedures (hence the name "procedural memory") such as stone tool knapping. It also includes the declarative knowledge of those skills (which we labeled connaissance).	
Enhanced working memory: we have postulated that the working memory of modern *Homo sapiens* was enhanced by a mutation approximately 50 to 100 Ka. Thus, Neanderthals possessed working memory but it did not have the same capacity of modern humans.	
Working memory capacity is a general ability or domain-free capability to control attention and maintain relevant stimuli in the face of interference. It can be enhanced by any increases in capacity by its domain-specific components.	

the first, this mutation accompanied the evolution of anatomically modern humans sometime prior to 150 Ka in Africa, where it then enabled the gradual development of modern behavior [a scenario favored by, for example, McBrearty and Brooks (2000)]. In the second, the mutation occurred after 100 Ka and produced behavioral modernity in groups that were already anatomically modern. This scenario is favored by Klein and others (e.g., Mithen, 1996; Klein and Edgar, 2002; Klein, 2003). In either case, modern humans with enhanced working memory entered Europe sometime after 50 Ka, leading to the eventual demise of Neandertals (see Table 1 for definitions of terms associated with working memory).

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Long-term working memory

Paradoxically, perhaps, one of the abilities that remain relatively intact when EWM capacity is removed is skilled, expert knowledge. One of the most famous neuropsychological case studies involved a patient known as H.M. After a bilateral hippocampectomy (which essentially severed his ability to store any verbal long-term memories, leaving his procedural memory system intact), H.M. could "recall" old procedural skills and transfer new ones to long-term procedural memory, but he could not verbally recall doing so (Milner et al., 1968). Experts are able to access and also encode information very rapidly, but only in the narrow domain of their expertise. To explain this ability, Ericsson and colleagues developed the concept of long-term working memory (henceforth L-TWM) (Ericsson and Kintsch, 1995). One of the characteristics of classic working memory is rapid fade: unless actively maintained by repetition (rehearsal), information held in working memory fades very rapidly, and is lost in a matter of seconds. If an experimental subject is distracted while performing a WM task, she cannot pick up where she left off because the information is gone. But Ericsson (Ericsson and Kintsch, 1995; Ericsson and Delaney, 1999; Ericsson et al., 2000) found this not to be true for experts processing information in the areas of their expertise. Chess masters, for example, are able to assess a chess position very rapidly and, when the position is removed from view, can return it to mind with virtually no loss of information, even when distracted. Musicians often demonstrate similar abilities, as in the famous example of Mozart learning a complete motet on one hearing (Gutman, 1999). This ability is domain-specific; it is not a general memory ability, but a very specialized ability linked to the information of one area of expertise. Because it does not fade, the information must somehow be entered rapidly into long-term memory, a process that usually takes many repetitions, or a longer time in attention (about 10 seconds) than short-term memory. Most long-term memory is also less reliable than short-term memory, yet the reliability of expert memory rivals that of short-term memory. Here, then, is a form of memory that is fast, reliable, and does not fade, but is very narrowly focused. It is clearly an important cognitive process for everyday activity and, indeed, appears to underpin our most impressive feats of cognitive power.

Ericsson and colleagues have proposed a model for L-TWM that can account for an expert's ability to encode information into, and retrieve information from, LTM very rapidly. The model is based on retrieval cues and retrieval structures. A cue is an item of knowledge (a "chunk" in memory terms) that is linked by association to a longer encoding [Ericsson suggests that the cue "reinstates the conditions of encoding" (Ericsson and Kintsch, 1995)]. A retrieval structure is a set of retrieval cues that the expert creates over time and which is relatively stable. Using chess as an example, when a chess master sees a chess position, his or her chess retrieval structure rapidly encodes the positions into LTM using retrieval cues (for example, the cue "Sicilian defense" allows immediate encoding of the relative position of thirty two pieces); he or she does not need to encode the specific board location of each piece. Later, if the board is removed, or if it is a blind chess demonstration, the master accesses the encoded information using the same cues (for example, "Game #2 is Sicilian defense"). The key element here is the retrieval structure, but expert retrieval structures are *not* easily acquired. One acquires them through extensive practice and analysis. Ericsson, following the literature on skilled knowledge, suggests that ten years is a good estimate of the time necessary to achieve mastery-level expertise in fields like chess or music (Mozart was fourteen at the time he copied the motet and had been composing since he was four). The resulting retrieval structure can assess a huge range of situations very rapidly because of the breadth its retrieval cues. The result is, somewhat counter-intuitively, a powerful and flexible kind of thinking. But it is limited to a narrow domain. The retrieval structure of a chess master is useless in playing Go, or even checkers, and indeed is only slightly better than average at remembering chess boards on which pieces have been placed randomly. L-TWM is not inherently innovative; it can rapidly assess and respond to a huge range of familiar situations and problems, but is not adept at creating truly novel responses because the retrieval structure and cues are stable, linked elements of long-term memory itself.

Neuroimaging studies appear to corroborate Ericsson's model. In fMRI studies of chess playing and Go playing, Atherton et al. (2003a,b) found that the areas of cortex normally activated in working memory, the dorsolateral prefrontal cortex in particular, are minimally activated (though, interestingly, more for Go than for chess). Instead, a more diffuse activation pattern is present, as one would expect from activation of long-term memory.

While Ericsson emphasizes the performance of experts, this kind of thinking is not confined to a few accomplished individuals. It is a style of thinking employed by everyone in their own areas of experience and expertise; it is simply most easily recognized and studied in exceptional individuals. Ericsson's model of L-TWM is, in fact, very similar to accounts of technical thinking provided by cognitive anthropologists. Even though Ericsson emphasizes the role of semantic cues in L-TWM, there is no reason that cues cannot also be images, or even "muscle memories," which are relatively precise patterns of muscle action learned by multiple repetition that can be deployed without conscious direction (e.g., a fencing parry). This is especially clear from a characterization of blacksmithing provided by Keller and Keller (1996).

Technical cognition

The most important similarity between Ericsson's model of L-TWM and technical cognition lies at the behavioral level. The technical expert learns his or her craft in the same way that all experts learn—by observation, analysis, and practice. The ten-year term cited by Ericsson as a norm for acquiring expert knowledge is essentially the same as is necessary to develop from apprentice to master in any craft. Superficially, at least, all expertise appears to share this learning curve. But do craft experts rely on retrieval cues and retrieval structures? This is a harder question to answer and requires comparison of two rather different approaches to cognition—the experimentally based studies of cognitive psychology and the ethnographic and participant-based studies of cognitive anthropology. The experimental approach is good at isolating and investigating specific cognitive components and producing replicable results. The ethnographic approach is good at describing the richness and complexity of real-world tasks. The methods are different but, as we hope to show, the results are comparable.

The Kellers' (Keller and Keller, 1996) study of blacksmithing emphasizes a phenomenological/action theory approach to understanding cognition, and the clarity of its presentation allows reinterpretation in light of some of the narrower concepts of cognitive psychology. In characterizing the cognitive life-world of the smith, the Kellers introduce three useful concepts—stock of knowledge, umbrella plan, and constellation. The stock of knowledge consists of the pool of information acquired by the smith during years of practice. Although it includes semantic information, it consists primarily of visual, tactile, and aural images of results, materials, and procedures. When a smith begins a task he or she first conceives an umbrella plan, which is "… the smith's mental representation of an ultimate goal for production and his associated general overview of the step-by-step procedures required to attain an end" (Keller and Keller, 1996: 90). This umbrella plan may contain semantic knowledge-names of materials, estimates of time, costs, etc., but it is also made up of visual, tactile, and aural images. The plan is executed using constellations, which are "… configurations of ideas implements, and materials …" (Keller and Keller, 1996: p. 91), that enable the completion of one step in the process. A constellation is not simply a mental image; it includes, and indeed is constituted through, the actual tools and materials. The visual, kinesthetic, and aural features of the tools and materials structure the nature of each particular step in a procedure as much as any semantically declarative knowledge. There is active feedback between the actions of the smith and his or her constellation until the step is completed or, if it fails, is begun anew with a revised constellation. In common procedures, these constellations may become recipes that are deployed with little active reflection, though the mutually constituting roles of tools, materials, and procedures still operate.

Even with this superficial presentation of the Kellers' account, it is possible to identify similarities with Ericsson's account of expert performance. First, the stock of knowledge is clearly content held in LTM. Much of this knowledge consists of procedural memories as well as declarative knowledge. It is much richer in content than the narrow domains usually tapped in experimental studies of LTM, especially in the importance of non-semantic information in the guise of visual and kinesthetic images, but there is no reason to suppose that it is stored differently. Umbrella plans would appear to be constructed using retrieval structures. The task at hand calls up the appropriate retrieval structure, held in LTM, which contains retrieval cues that tap into associated knowledge. What is different about an umbrella plan is that the retrieval structure includes many non-semantic cues. Constellations are retrieval structures linked dynamically to tools and materials. Here the two-way role of retrieval structures is apparent. Not only do the cues access appropriate images and procedures, they enable rapid encoding of new information in LTM, adding to the smith's stock knowledge. Short-term working memory is also engaged in constellations.

A constellation deployed by L-TWM does not exhaust the attention capacity of working memory, especially during routine tasks that have become recipes. The free attention capacity can be used to innovate, plan ahead, or, more dangerously, daydream. The retrieval cues themselves often consist of image associations: "A glance at a tool may trigger an idea for production" (Keller and Keller, 1996: 94). Such non-semantic retrieval cues are essential elements of all technical activity, but are no different than the semantic cues emphasized by Ericsson (indeed, we suspect that many of the cues used by chess masters may also be visual images).

Ericsson and colleagues have stressed the study of experts because extraordinary performance both calls out for understanding and, because of the saliency of expert activity, permits ease of study. But clearly L-TWM is not a cognition possessed only by an accomplished few. As the work of the Kellers exemplifies, it is a style of thinking that is deployed in many human activities; indeed, we contend that it is the style of thinking that is most commonly used in everyday tasks. That some have achieved mastery levels of skill reflects the years of concentrated practice necessary to acquire a stock of knowledge, including an array of relevant retrieval structures for successful completion of a huge array of potential tasks.

We believe that Neandertals regularly employed L-TWM that was as effective as any documented for modern humans. The evidence lies in the archaeological record, primarily in the reconstruction of skilled performance in lithic reduction procedures.

Levallois reduction

Over the last twenty years palaeolithic archaeologists have moved away from an emphasis on stone tool typologies, which focuses on tools as products, to an emphasis on the entire use-life of stone artifacts—from initial raw material acquisition and distribution to discard. Middle Palaeolithic (MP) assemblages have played perhaps the key role in this reorientation, with Dibble's critique of typology and demonstrations of MP reduction sequences (Dibble, 1987), and Boeda's (Boeda, 1994) reconceptualization of Levallois being landmark contributions. This reorientation is based largely on two methods. The first documents sequences through careful analysis of artifacts, cores, debitage, and experimental replication (Boeda, 1994, 1995; Chazan, 1997). The second documents sequences through refitting cores (Van Peer, 1992, 1995; Schlanger, 1996; Chazan, 1997). The two approaches have succeeded in providing a detailed description of sequences of action required in the production of MP artifacts. These descriptions are sufficiently detailed and comprehensive to stand in place of prehistoric actors in a cognitive analysis. To put it another way, it is very unlikely that prehistoric knappers used sequences of action that have not been identified.

Levallois is the most informative of the MP reduction techniques. We do not, of course, intend to equate Levallois with Neandertals. Its first appearance in the archaeological record, for example, antedates the appearance of Neandertals. Moreover, comparable reduction techniques were used by anatomically modern humans in Africa and the Near East. However, Neandertals did use Levallois and its variants for thousands of years, and it remains the best described example of sequentially organized action in the Neandertal record.

Levallois is a technical process or reduction procedure, not a tool type (Van Peer, 1992; Boeda, 1995; Chazan, 1997). It is a general procedure in which a core is prepared for the ultimate removal of one or several flake blanks, which then may or may not be further modified. The procedure produces a variety of preparatory, intermediate, and final products that document a complex sequence of actions. "The repetitive pattern of Levallois surface preparation evidences a desire for standardized morphological control of a limited number of blanks" (Van Peer, 1995: 4). These blanks are "determined" in the sense that a sequence of actions, the chaine operatoire, constrains the final product. It is not, however, necessary that the knapper have an image, a "mental template," of the final blank (Schlanger, 1996; Chazan, 1997). In general, there are three basic steps in the procedure. The first prepares a core with two distinct but related surfaces, one, a more convex platform surface that will include the striking platform, and a second flatter production surface from which the blank or blanks will be removed. The second step prepares the striking platform itself in relation to the axis of the intended blank. The third step is the removal, by hard hammer, of the blank or blanks. The first two steps each encompasses its own sequence of action, as does the final step if multiple blanks are removed. Levallois is not a single, invariant procedure. There are two basic varieties—"preferential" for the removal of a single final blank and "recurrent" for the removal of two or more final blanks (Boeda, 1995). Recurrent Levallois itself has many variants—unidirectional, bi-directional, and even centripetal (Chazan, 1997), and each requires a different approach to core and platform preparation. "The crucial point, which has been demonstrated repeatedly through experimentation, is that the configuration of the two faces must suit the specific recurrent method employed" (Chazan, 1997: 726). Cores can be, and were, reused by preparing the platform and production faces anew, and striking off a second blank, or second set of blanks. This invariably requires an adjustment of technique because the mass of the core has been much reduced.

The complexity of the task, and the comprehensiveness of the accounts, invites a cognitive interpretation. In a sense, some archaeologists have already taken this approach in describing two major components of the knapper's mind: connaissance, which is the knowledge held by the knapper, and savoir faire, which is the motor skill required for performance (Boeda, 1995; Chazan, 1997). It is also possible to articulate the accounts of Levallois with cognitive anthropology and cognitive psychology. The Kellers' concepts of stock of knowledge, umbrella plan, and constellation can be directly applied.

The sequence of actions that can be reconstructed for Levallois reduction resembles the sequence of action documented by the Kellers for blacksmithing: a sequential task with definable steps during which the artisan makes choices among a variety of specific techniques and procedures in order to complete each step and, ultimately, produce a finished product. At this purely descriptive, qualitative level of comparison, there is no obvious distinction between the two activities, especially if we compare Levallois reduction to the "recipe" procedures of blacksmithing (procedures used in often-performed tasks). But are the cognitive underpinnings the same, that is, did Neandertal stone knappers have stocks of knowledge, make umbrella plans, and use constellations? We can only answer these questions by using modern knappers as surrogates. Given the descriptive similarity between Levallois and modern technical activity this strikes us justifiable, if not ideal. We have already seen that a technical analysis of Levallois, based on experimental knapping and refitting, identifies two components to cognition, connaissance and savoir faire. Both are clearly components of the knapper's stock of knowledge, with former being the declarative-component and the latter being the skilled procedural and motor component. Equally clearly, both are acquired through extended periods of practice. It is apparent that much of this knowledge must be held in the form of visual, tactile, and even aural images concerning raw material, knapping qualities, edge angles, angles and force of delivery, and so on. Most palaeolithic archaeologists, for example, understand at least some of the declarative knowledge necessary to produce a Levallois flake, but very few are capable of actually doing it because they lack the necessary non-declarative knowledge and skill. The connaissance and savoir faire of Levallois knappers clearly constitutes a stock of knowledge that one acquires with years of practice. This stock of knowledge includes a large range of alternative procedures—recurrent bi-directional, preferential, etc.

Experimental archaeologists and refitters have not explicitly identified cognitive components directly comparable to umbrella plans and constellations, but their accounts suggest that these interpretive concepts are appropriate. Boeda (1995: 46), for example, refers to the "volumetric conception of the core" in the guise of "two assymetrical [sic] convex secant surfaces." Baumler (1995) distinguishes between strategy and sequence. "Reduction strategy refers to the goal(s) of the knapper, while sequence or sequences more narrowly represent the method of achieving goals" (p. 17), and "… From beginning to end, the reduction of a core is characterized by adjustments to changing parameters—some predictable, others less so, and some not at all" (p. 17). The awkwardness of the wording attests to the non-semantic nature of this conception. This visual image would appear to orient each step of the process; it is, in essence, the key feature to an umbrella plan developed by the knapper prior to beginning each step. The analog to constellations lies in the actual execution, which incorporates raw material, available hammers, muscle tensions, visual and aural images, and the feedback from the process itself. In sum, Levallois reduction, at least as performed by modern knappers, fits easily into the Kellers' model of technical cognition. More importantly, there is no valid reason to believe that Neandertals performed Levallois reduction differently; in other words, their technical cognition appears to have been the same as that of modern humans.

Levallois reduction also fits the criteria for expert performance and results from the deployment of Ericsson's L-TWM. The connaissance and savoir faire of knappers are clearly information stored in long term memory. That much of this information is non-semantic simply corroborates the importance of visual, tactile, and aural imagery in technical expertise. That modern archaeological studies do not identify a specific cognitive structure or style that can be equated with retrieval cues and retrieval structures is not a surprise. Ericsson's research and that of Boeda and van Peer do not overlap in terms of specific theory, concepts, or citation universe. There are, nevertheless, good reasons for concluding that Levallois reduction employed retrieval cues and retrieval structures. First, one learns knapping in the same manner as one learns every task—by experience and analysis. Levallois is one of the more difficult techniques to learn, and mastery emerges only after years of practice. From Ericsson's perspective, a knapper must acquire a large suite of retrieval cues organized into retrieval structures appropriate to a huge variety of specific circumstances (raw material, nodule shape and size, imperfections, results of preforming, results of face preparation and platform preparation, re-preparation, and so on). Second, the dynamic nature of Levallois reduction suggests not just constellations, but the retrieval structures on which they are based. Modern knappers change their strategy based on changing conditions, and it is clear that prehistoric knappers did as well. "The data presented here, based on the complete sample of cores and the entire series of both Levallois and non-Levallois flakes, clearly indicate that flaking patterns did indeed change as a function of the degree of core reduction" (Dibble, 1995: 102). More specifically, we suggest that the "volumetric conception of the core," as described by Boeda and Chazan, is itself a retrieval structure. It consists of an interrelated set of cues that call up much larger encodings of the Levallois procedure that are held in long term memory. The cues include the various convexities of the platform and production surfaces, edge angle at the striking platform, orientation of ridges that direct the force, and so on. The larger encodings held in long term memory include a huge array of information learned in previous knapping episodes (and encoded through the retrieval structure), some of which is declarative knowledge, but most of which consist of images (visual, tactile, and aural), motor procedures and the muscle tensions tied to skilled activity.

The validity of applying L-TWM retrieval structures to prehistoric examples of Levallois is corroborated by Schlanger's (1996) masterful analysis of a refitted core from Maastricht–Belvedere (a MP site in the Netherlands dating to OIS 7). In reducing the core, the knapper produced nine Levallois flakes in seven distinct phases. Toward the beginning of each phase the knapper identified a particular configuration of the production surface to act as the distal convexity (opposite the future striking platform), and then trimmed the lateral convexities and the platform itself. In three of the phases he or she employed a "preferential" strategy, and in three other, a "recurrent" strategy. For each phase he or she had to modify the plan to adjust to the ever shrinking size of the core. This account fits nicely into the Kellers' concepts of umbrella plan, in this case the overall approach to the core, and constellations, in the execution of each phase. Flexibility is apparent in the ease of shifting from preferential to recurrent and back again. But most telling of all, the knapper clearly used the "distal convexity" as a cue to call up an appropriate retrieval structure that was then used to guide subsequent preparations of the core. As we saw with blacksmithing, this reliance on the retrieval structures of long term working memory is characteristic of expert performance. From this perspective Neandertal expert technical cognition is indistinguishable from that of modern humans.

This account of Neandertal expert cognition bears on, but certainly does not resolve, several long standing problems in MP research. It adds most usefully to our understanding of variability and innovation. It has long been recognized that European MP assemblages varied in terms of relative percentages of individual artifact types, relative predominance of knapping techniques, and in the presence and absence of certain diagnostic types (e.g., handaxes or backed pieces). The degree of variability within the European MP appears to have been greater than that recognized for earlier periods, but not as great as that recognized for the late Upper Palaeolithic [the apparently intrusive early Upper Palaeolithic Aurignacian was, initially at least, less variable than the local Middle Palaeolithic (Kozlowski 2000)]. Archaeologists have interpreted this variability in a variety of ways: Bordes (1968) argued for ethnic differences, Binford (1973) for functional differences, Mellars (1969, 1973) for chronological differences, and Dibble (1987) for differences in reduction sequences, resharpening, and the use-life of tools. Our current account of expert cognition fits best into recent interpretations by Mellars (1996) and Gamble (1999). Mellars argues that most of MP variability can be understood as resulting from relative social isolation and technological drift. This is precisely what one would expect of a technology based entirely on expertise. Because knapping retrieval structures are stable but flexible strategies of production, they can adjust to changing circumstances such as availability of raw material (size, quality, ease of access) or the demands of specific tasks (butchering freshly killed bison as opposed to scraping reindeer hides). Simple deployment of the L-TWM stocks of knowledge in varying circumstances would yield varying products. Moreover, expert retrieval structures take time to learn—years, in fact—providing ample opportunity for minor intergenerational drift in techniques. Major changes would be rare, and occur only through serendipitous discovery (e.g., a major blunder with a fortuitously good result) or the arrival of new technologies that could be copied (see below). L-TWM is also consonant with Gamble's (1999) more audacious argument that Neandertals acted in "landscapes of habit." According to Gamble (1999), a Neandertal lived out his or her life on a geographic scale with a radius of perhaps only 20–30 km, with occasional ventures of longer distance. "Within the regional scale represented here by the landscape of habit and measured by raw-material transfers, the effective networks of individuals structure the degree to which social life was extended [i.e., no large scale social groups]. I therefore conclude that life was still very local and usually immediate" (p. 242). Such a scale could easily be organized and exploited through retrieval structures built on very specific cues in the local environment. Neandertals would truly have been experts of their local domain, so much so that new arrivals would be hard pressed to compete. But Neandertals would have had a more difficult time coping with large, interregional spaces, and would be seriously handicapped for any task requiring long range planning (spatially and temporally).

A technology based solely on L-TWM would not be innovative, if by innovative we mean experimentation with new forms and techniques. The question of creativity is a contentious one in discussions of human evolution, but here we side with Mithen (1996, 1998). Even though Neandertals' technology did vary and change, it did so on a scale and at a rate that would appear to rule out conscious experimentation and creativity. These are, we contend, the stuff of enhanced working memory. The reason Keller's blacksmithing is not identical to Neandertal knapping is that EWM provides freed-up attention capacity. Especially when L-TWM has converted umbrella plans to recipes, the smith has processing capacity available to make unique comparisons, think further ahead, or daydream. One result of this is innovation. We have no reason to conclude that Neandertals ever did this. L-TWM worked well for them and provided sufficient flexibility to solve all of their immediate problems. But their day-to-day life consisted of recipes and an endless "drive to work."

Our discussion has focused on Neandertals because they are known to have used the Levallois technique, and are otherwise the best known pre-modern hominid. They were certainly not alone in demonstrating reliance on expert performance. Other late Pleistocene hominids used Levallois and other prepared core techniques of equal complexity. Our characterization of Neandertal cognition applies to these hominids as well. One group of these, perhaps McBrearty and Brooks' (McBrearty and Brooks, 2000) *Homo helmei*, eventually gave rise to anatomically and behaviorally modern humans with enhanced working memory.

Neuropsychology

There is some interesting evidence from neuropsychological studies of normally functioning adults who have naturally restricted working memory that corroborates this picture of Neandertal cognition. Kane and Engle (2002) have investigated the role of the prefrontal cortex in working memory, its executive functions, and their relationship to intelligence from an individual-differences perspective. They first established, through numerous empirical studies of evidence, the important role that the prefrontal cortex plays in both working memory and executive functions, especially their overlapping roles in attention to relevant tasks. They view this focused attention as a central feature of the prefrontal cortex and note that a critical aspect is the maintenance of attention in spite of competing but irrelevant stimuli. Interestingly, as previously noted, working memory capacity has been shown to be strongly correlated to both general intelligence and fluid intelligence (e.g., Kyllonen, 1996; Kane and Engle, 2002). Kane and Engle also argue that typical short-term memory tasks (verbal memory of lists of words) are not correlated as well with intelligence and working memory capacity because these tasks do not generally employ distraction. They postulate that maintenance of attention in the presence of interference is the critical control function of working memory capacity. Kane and Engle used various working memory tasks on normally functioning participants and divided them into two extreme groups, those with the highest working memory spans and those with the lowest working memory spans. They found that that the lowest span participants were more susceptible to long-term memory interference, including retroactive and proactive interference. If Neandertals did have restricted working memory capacities, then they would have had greater difficulty in solving a new task because of prior habits of thought. Kane and Engle have also demonstrated that lower capacity participants also have a much greater vulnerability to outside interference, particularly when there is competition between the new task goal and old habitual responses. For Neandertals, this might have meant they had more difficulty changing their ways of manufacturing tools after 200,000 years of sameness, given their skilled-cognitions, especially motor skills, which often require many more trials to master than do verbal skills. With EWM, modern humans may have had a distinct advantage defending against the interference from habitual responses, both verbal and motor. Kane et al. (2001) have also demonstrated this same vulnerability to interference of low capacity participants to attention-capturing visual tasks. Conway et al. (2001) have found similar results in verbal acoustic-attention tasks. Those participants with lower fluid intelligence had similar failed goal maintenance in the presence of interference as those participants with lower working memory capacity (e.g., Duncan et al., 1996), further supporting the link between working memory capacity and fluid intelligence. In summary, there is some neuropsychological basis for thinking that Neandertals may have had trouble adjusting to novel conditions, particularly those that might have required new ways of behaving outside the range of their individual expert abilities.

In sum, psychological, anthropological, archaeological, and neuropsychological evidence come together in a way that allows us to draw a picture of Neandertal cognition. Neandertals regularly employed an expert cognition fully as effective as that used by modern humans. Such expert cognition was very effective and flexible, and able to deal with all of the problems of Neandertal life, much as it deals with most of the problems in our everyday life. What was missing from Neandertal cognition was the enhancement of working memory that enabled regular innovation and experimentation.

The Chatelperronian

This model of Neandertal cognition also helps us understand the nature of information transfer evident in Chatelperronian assemblages.[1] Traditionally the modern elements found in the Chatelperronian have inspired interpretations of imitation or independent invention (d'Errico et al., 1998). Imitation advocates appear only to mean "learned from" rather than any of the more detailed definitions available from the comparative literature, where imitation requires copying at least part of a specific motor sequence (Tomasello et al., 1987; Whiten and Ham, 1992; Tomasello, 1994). The nature of Chatelperronian stone tools, and the apparent expertise of Neandertal stone knappers, actually suggests that Neandertals acquired modern features through "emulation." This is a form of observational learning in which the subject understands the goal but invents his or her own procedure for achieving it. For the Chatelperronian this is most apparent from the technique of blade production. There can be little doubt, given the flexibility inherent in retrieval structures when applied to familiar problems, that Neandertals could learn prismatic core techniques by applying retrieval cues and structures developed over a lifetime of stone knapping. But for Chatelperronian blades, the Neandertals used large, thick flakes or small blocks for cores, and removed the blade along a prepared crest (d'Errico et al., 1998: S 13). This is unlike true prismatic core technique, and a bit like Levallois in its emphasis on prepared surfaces, which is precisely what one would expect if Neandertals invented their own technique, i.e., emulated the goal of blade production. Given the sophistication of Levallois retrieval structures, examination of a blade from a prismatic core would have been sufficient to generate a problem solution. Such cues as ridge orientation, convexities, striking platform, and so on, would have called up possible solutions from long-term memory. Minimal trial and error would have soon produced the solution we see in the archaeological record. Similar goal emulation could have produced all of the modern elements we see in Chatelperronian culture without the necessity of invoking instruction or direct observation of the procedure. In other words, it is not necessary that Neandertals ever directly observed modern human knapping; they could have reconstructed a procedure by observing the debitage alone. Indeed, the nature of Chatelperronian knapping suggests that Neandertals rarely, if ever, directly observed a modern human knapping. Given the sophistication of their own knapping abilities and retrieval structures, they almost certainly would have been able to reproduce prismatic core techniques as precisely as if they had actually observed the procedure. We present these arguments in more detail elsewhere (Coolidge and Wynn, in press).

Neandertal personality

There is no widely accepted definition of the term "personality" in psychology; indeed some personality textbooks eschew a single definition entirely. It has often been defined globally as the sum total of a person's behavior, and it has also been defined eclectically vis-à-vis a specific psychological theory, e.g., Freudian psychoanalytic

1 We are fully aware of the controversy concerning the chronology, stratigraphy, taphonomy, and typology of Chatelperronian and early Aurignacian assemblages in western Europe (Mellars, 1996, 1999; d'Errico et al., 1998; d'Errico, 2003; Zilhao and d'Errico, 1999; Conard and Bolus, 2003). Our interpretation presumes some temporal overlap between Neandertal and modern human populations, and in this sense comes down on the side of acculturation rather than independent development. Indeed, given what we have been able to reconstruct about Neandertal cognition, independent development of the Chatelperronian over such a brief period strikes us as unlikely.

theory (Larsen and Buss, 2002). Nonetheless, some of its accepted attributes are a set of traits, processes, or mechanisms that are relatively enduring and influence social and environmental interactions. Tattersall (2002) has recently pronounced "We have no idea what the Neandertals were like temperamentally: whether they were aggressive or retiring; cooperative or individualistic; forthright or sneaky; trusting or suspicious; crude or lovable; or like our own species, all of the above. For all that we know about Neandertals from the impressive record they left behind, we are still unable to form a psychological profile of these hominids that might help us to divine how they might have interacted with this new element [Cro-Magnons] on the landscape." (pp. 129–130). But is our knowledge of Neandertal personality this bleak? Does it actually require divine intervention, or does the archaeological record and neuropsychological theory offer us a basis for speculation? We think the latter, and shall briefly review the pros and cons of the archaeological evidence of Neandertal subsistence strategies, archaeological evidence for symbolism, anthropological evidence for language, and ground our hypotheses accordingly.

Neandertal hunting has long been a topic of debate and disagreement. Binford's extreme argument (Binford, 1989) that Neandertals were obligate scavengers has given way to a more eclectic picture in which Neandertals employed a variety of hunting techniques. d'Errico (2003) reviews evidence that Neandertals were clearly expert hunters of a wide range of large mammals, including dangerous species, and concludes that once the zooarchaeological evidence has been carefully examined "… little remains to distinguish the subsistence strategies of Neandertals and anatomically modern humans" (p. 5). However, evidence from bone trauma suggests that Neandertals may not have been quite as modern as d'Errico envisions.

Berger and Trinkaus (1995) found similar postcranial trauma patterns between Neandertals and rodeo athletes, with high levels of head and neck injuries, as well as high frequencies of shoulder and arm injuries. Neandertals' low population densities appear to make interpersonal violence and bellicose behavior a less attractive causal hypothesis and dangerous hunting strategies a more likely one. They concluded that Neandertals probably killed their quarry from close range. The spears were almost certainly thrust, not thrown. Success in such an endeavor relies, ultimately, on personal expertise—knowledge of animal behavior, timing of the rush, placement of thrusts, pursuit of wounded animals, deception of other members of a herd, etc. This kind of hunting is truly dangerous and, even for modern hunters, requires skills learned over years. But unlike modern hunters, Neandertals appear to have been largely opportunistic. Neandertals hunted what was available and almost certainly could be selective when appropriate (Gaudzinski and Roebroeks, 2000; but see also Munson and Marean, 2003). They were very effective hunters, indeed good enough to flourish in a relatively hostile European glacial environment, but they do not appear to have "tweaked" the system by developing closely scheduled seasonal systems, altering the landscape, or developing storage and remote capture systems (Wynn and Coolidge, 2003). In addition to the pattern of traumatic bone injury, Trinkaus (1995) found high levels of general wear-and-tear, and degenerative bone disease, but he found not a single case of a healed lower limb injury that would have prevented mobility. This led him to suspect that the maintenance of locomotion was an absolute necessity in daily Neanderthal life and those who were not mobile were left behind. All of this is entirely consistent with the model Neandertal cognition presented above; long-term working memory could provide a flexible and effective set of hunting techniques that would work in a wide variety of specific circumstances. Psychological traits that may be inferred from these, particularly the hunting of more dangerous species, might include bravery, low levels of harm avoidance, and perhaps greater difficulties in making cost-benefit analyses. Thus, a kind of stoicism may have been the norm among Neandertals. From a contemporary social perspective, one might be tempted to add cruelty, although current psychological thinking might require amusement as a motivation for the cruelty, or cruelty for the sake of dominance establishment.

Symbolic capacity and language

Reconstruction of many aspects of Neandertal mental life hinges on an understanding of symbol use and language. Below we treat them separately.

Symbol use in general has long been linked to frontal lobe function (e.g., Luria, 1966). While symbolic reference, per se, probably does not depend on working memory, the use of symbols certainly would. Symbols are tokens that can be held in attention, and manipulated by working memory, so any enhancement of working memory would provide greater capacity for the deployment of symbols. If Neandertals and modern humans did differ in their working memory capacity, we would expect there to have been some difference in their use of symbols. Despite serious methodological problems, linked largely to taphonomic processes, the archaeological record for mortuary treatment and art appears to support this scenario.

By 30,000 years ago, modern human burial included features unknown for Neandertals. One of the best examples is from Sungir in Russia, which dates to about 32,000 to 30,000 (White, 1993). This site contained the remains of a young boy covered with strands of beads, 4903 in total. He wore a cap of beads with fox teeth attached. His belt contained over 250 polar fox canine teeth, which required a minimum of 63 hunted or trapped fox to produce it. In his grave, there was also a carved mammoth ivory pendant and a carved ivory disc. Beside him was also a mammoth ivory lance, much too large and heavy to have been a practical hunting weapon. An adjacent grave contained the body of a young girl with 5247 beads and other objects (but curiously, no fox teeth). White (1993) has estimated the time to fashion the beads might have required over 3500 hours. At Qafzeh in Israel a burial of a modern human dating to between 90 and 110 Ka (Schwarcz et al., 1988) includes personal ornaments [perforated and color-stained shells (d'Errico et al., 2003)]. Such burials stand in stark contrast to Neandertal burials, where there are few, if any, convincing examples of grave goods. White et al. (2003) have recently documented a much earlier example of probable mortuary (or at least post-mortem) treatment of corpses. On the three Herto skulls from Ethiopia, which date to between 160 to 154 Ka, White and his colleagues found evidence of post-mortem defleshing and polishing. These are skulls of anatomically modern humans. It is impossible, of course, to identify specific symbolic meanings to such actions, but nothing like it has so far been identified for Neandertals.

Evidence for Neandertal art is meager. They did use ochre and other mineral pigments (d'Errico et al., 2003), and did produce enigmatic nonfigurative engravings on bones (Bednarik, 2003). There is nothing, however, that approaches the artistic performances of European Upper Palaeolithic artists. Lewis-Williams (2002) sees the demands of two-dimensional cave art as requiring much greater cognitive ability than Neandertals were likely to have possessed. For Lewis-Williams, the representational pictures of cave art, along with highly ritualized burials and carvings, implied that modern humans had a hierarchical, or at least differentiated, society that was not simply based on age, sex, or physical strength. The bulk of this evidence also leads Lewis-Williams to speculate that Neandertals had a different form of consciousness from modern humans and that their mental imagery may have been more closely tied to their skilled motor cognition.

The archaeological record for symbolic behavior is controversial, to say the least [see the recent review by d'Errico et al. (2003)]. We are not suggesting that Neandertals lacked symbolic ability, only that the archaeological evidence for symbol use among Neandertals is far less extensive than it is for modern humans. This is in keeping with our hypothesis that the difference lay in the capacity of working memory.

Because our model of Neandertal mental life relies on a relatively lower capacity for working memory, we must consider the potential effects of this on language. The relatively minor genetic mutation we have proposed may have increased the length of phonological storage of modern human working memory, and this enhancement in phonological store may have had a significant impact on language. Modern neuropsychological assessment methods typically measure phonological storage by the Digit Span subtest of the

Wechsler Adult Intelligence Scale (e.g., Lezak, 1995). The Digit Span subtest requires participants to repeat increasingly long strings of numbers forwards and then backwards. Interestingly, this subtest usually produces the lowest correlation with IQ among all other subtests (although it does correlate strongly), and it is thought to be a better measure of attention than of IQ. If modern humans benefited from a mutation-based increase in phonological storage, then the neural cognitive architectural differences need not have been much different from that of Neandertals. In fact, they could have been nearly identical. Phonological storage, as Baddeley and Logie (1999) have recently proposed, may be the bottleneck of language comprehension and production. Increased phonological storage may have allowed modern humans greater articulatory rehearsal, allowing for better long-term storage, greater self-reflection, and the beginnings of introspection and self-reflection. Greater phonological storage would have allowed increases in syntactical complexity. Sentences could be longer and contain more information, and they could also be imbued with more meaning through syntactical embedding. A greater phonological store might also permit greater morphemological richness. While the native ability to produce different morphemes might not have been directly affected, the ability to hold and maintain new and various morphemes might have been enhanced by an increase in phonological storage.

The increase in phonological storage might also have increased the pragmatics of speech, including an enhancement of modes of speech. For example, simple declarative sentences could now contain more information. Commands (imperative mode) could become more complex. Questions (interrogative mode) could contain more specific information as well, and the results might have been greater efficiency, clarity, and more effective communication.

The creation and enhancement of the subjunctive mode of speech [Klein and Edgar's (2002) "what if" statements] or the greater development of the future tense in language due to an increase in phonological storage requires particular attention. In part, because of its highly transient nature, working memory would not necessarily benefit from memories of the past, stored in long-term memory. So how would phonological storage aid the prediction of the future? Baddeley (2001) proposed that working memory would allow for the reflection of multiple past experiences. This might allow the individual to actively choose a future action or create an alternative action, rather than simply choosing the path of most probable success. Although an individual would still be better off (compared to one without benefit of past experience) choosing alternatives simply based on the past, Baddeley proposed that working memory would allow for the formulation of mental models of future behavior. Shepard (1997) described a similar working-memory and long-term memory dichotomy. He postulated that natural selection favored a perceptual and representational system able to provide implicit knowledge of the pervasive and enduring properties of the environment (long-term memory) and that natural selection also favored a heightened degree of voluntary access to this representational system (working memory). This access, he proposed, facilitated the accurate mental simulation of varying actions, allowing the evaluation of the success or failure of these actions without taking a physical risk. Shepard thought that the mere accumulation of facts (as in Baddeley's semantic memory or Mithen's natural history intelligence or technical intelligence) would not result in advances in scientific human knowledge but its advancement would require "thought experiments." He also postulated that every real experiment might have been preceded by thought experiments (which we think is directed by working memory) that increased the probability of the success of the real experiment. Dawkins (1989) also proposed that natural selection would have favored the reproductive success of those organisms capable of simulation. He described systems highly similar to those of executive functions and replete with the executive functions metaphor. For example, he viewed consciousness as the culmination of an evolutionary trend in which consciousness served as executive decision-makers with the acquired "ability to predict the future and act accordingly" (Dawkins, 1989: 59).

Sugiyama (2001) has recently argued that narratives, folklore, or story-telling (all of which may be clearly categorized as episodic memories) may have been selected because they are an efficient and safe means of transferring information. Verbal representations are substitutes for time-consuming and sometimes dangerous first-hand experience. She posits that fitness in varying habitats may have particularly aided foraging knowledge by transmitting information about geography, plants, fauna, weather, and other aspects. We surmise that increased phonological storage would serve to create and store more elaborate stories (which thus contain greater information), and serve as a better and larger "stage" for their recall from long-term memory. Arsuaga (2001) has further postulated that Neandertals may not have had the myth-making and story-telling abilities possessed by modern humans, and that the latter's enhanced abilities kept them in better contact with their natural world, their peers (local and distant), and their ancestors.

An increase in phonological storage could have also aided in cross-modal thinking. Hermer and colleagues (Hermer and Spelke, 1996; Hermer-Vasquez et al., 1999) found that, in both children and adults, success in a cross-modal task requires the conjoint use of spatial vocabulary with non-geometric information in a single thought or memory (e.g., "it's to the right of the blue one"), and it is not dependent on IQ, age, or vocabulary size. As a whole, the findings support Carruthers's (2002) contention that language serves as the vehicle of inter-modular thinking, and we contend that increased phonological storage allowed language to "load up" additional information in a single spoken or subvocalized thought that gave modern humans their ultimate selective advantage over Neandertals. We believe the scenario would be the same if this minor genetic mutation was not specific to phonological storage but actually enhanced general working memory capacity, which is our speculation as to the nature of the genetic mutation. We believe the greater sophistication in behavior resulting from increased phonological storage would have been the same had the mutation involved an increase in working memory capacity.

Back to personality

So what does a lack of EWM, and an abbreviated phonological store, mean for Neandertals' personality? First and probably foremost, we think that there might have been dramatic language differences between modern humans and Neandertals. We contend that EWM enabled a cognitively different form of culture, as epitomized by the highly ritualized burials such as Sungir and ornate parietal art, with its implications for the presence of sophisticated and extensive symbol-based systems of thought. If we are correct, then the language of Neandertals may have been pragmatically restricted to declarative, imperative, and exclamatory modes of speech. Interrogative speech was probably more limited, and we hypothesize subjunctive speech may have been non-existent or severely limited, as was the use of the future tense. In this regard, modern humans would have seemed loquacious, while Neandertals might have appeared more laconic. Story-telling and narratives used by modern humans might have been as ornate as present-day story-telling, while Neandertal stories might have been simpler and less inventive (e.g., Arsuaga, 2001).

If we could look back in time, would we have seen Neandertals laugh less? Mithen (1996) is alone in addressing the issue of Neandertal humor, and he proposes a less humorous Neandertal. He bases his speculation on the presumed lack of integration between the natural history intelligence and social intelligence of Neandertals. This lack of cognitive fluidity, he postulates, would have put Neandertal at a disadvantage when attempting to appreciate appropriate incongruities, one important aspect of some types of humor. There are, of course, other types of humor, and there is no reason to suspect that Neandertals would not find some aspects of physical humor funny (e.g., much of the sort we call slapstick), particularly if the situation was appropriate. We speculate that Neandertal humor, given the hypothesized lack of EWM and a restriction in linguistic comprehension and production, might lack an appreciation for language-based humor, including plays-on-words and puns. Given that the archaeological record gives us a picture of the hardness and difficulties of daily living in Neandertal culture, might Neandertal humor have had an element of cruelty or might it have been devoid of humor completely?

The only neuropsychological basis for the latter speculation is a dangerous one: case studies of patients with frontal lobe dysfunction and interruptions of executive functions and working memory. The danger in the use of such studies lies in assuming the behavioral sequelae of brain damage are the same as the sequelae of restricted working memory. With this caveat in mind, frontal lobe-impaired patients (e.g., Levin et al., 1991) are generally reported as humorless or laugh inappropriately. Other symptoms include apathy, disinhibition, and emotional dysregulation. They usually lack initiative, creativity, and spontaneity. They most often speak only when spoken to. Their speech is sparse and frequently confined to simple declarative and imperative modes rather than the subjunctive. They often neglect personal hygiene and become unwashed and unkempt. They have narrow interests and do not engage in former hobbies, nor do they take up new hobbies or interests. They have a high tolerance for boredom. They are often seen as inflexible, preferring to stick to old habits and ways. Their families perceive them as easily angered or irritated. They are not typically guilt-ridden or overly anxious. They show little or no grief. More often than not, frontal lobe patients frequently lose interest in sex, although there are rare instances of hypersexuality. They are often immodest and crude. They are not overly wily and crafty. Their methods for getting what they want are more likely to be blunt and overt. They show little joy and have little empathy (showing reduced or absent ability to understand the perspectives of others). In the more strict definitions of executive functions, frontal lobe patients are usually indecisive, show poor planning abilities, and are disorganized when it comes to goal attainment. They have great difficulty with abstractions and metaphors. Innovation and creativity are completely absent. Finally, they often fail to complete tasks despite the ability to do so (e.g., Luria, 1966; Lezak, 1982; Levin et al., 1991; Mega and Cummings, 1994; Lezak 1995; Coolidge et al., 1996; Coolidge et al., 1998; Miller and Cummings, 1999; Goldberg, 2001; Stuss et al., 2001).

Again, there is danger is extrapolating from neuropsychological studies of frontal lobe brain-damaged patients to normally functioning ones. However, these studies do give some basis for reasoned speculation; we need not conclude that there is no basis whatsoever for postulating differences between Neandertals and other humans. Many of the personality traits listed previously may result from impairment of working memory, which is, after all, a well-established frontal lobe function. Many are in fact consistent with the model of Neandertal cognition presented earlier in this paper, i.e., heavy reliance on long-term working-memory, with little or no excess capacity for creativity and innovation. In the current state of understanding in neuropsychology, we cannot be more specific. However, the evidence is sufficient to conclude that Neandertal personality, while obviously perfectly normal for Neandertals, would have been very different from that of a typical modern human.

Conclusions

The preceding analysis has combined concepts and methods of three disciplines to draw a sketch of Neandertal cognition. We do not pretend that this is a comprehensive picture; such a feat is probably impossible. However, we believe that we have made a strong case for Neandertals' reliance on a long-term working memory capability that was essentially modern in scope. This ability is most apparent in the technical domain of stone knapping, but is also consistent with other archaeologically documented activities including effective hunting. We also believe that Neandertals' low levels of innovation and creativity attest to a lower capacity of working memory. We do not suggest that Neandertals had no working memory, only that its capacity was lower, either in terms of a smaller phonological store, or a reduced attention capacity. This cognitive profile has also allowed us to speculate about associated personality characteristics, including stoicism, tolerance for boredom, low levels of harm avoidance, and difficulties in cost benefit judgments. Reliance on long-term working memory clearly provided a very successful adaptation; L-TWM is a very flexible form of cognition that can respond appropriately to a huge range of new, but familiar situations. It is important to re-emphasize that most of what modern humans do is based on L-TWM. The enhanced working memory that appears to have accompanied the evolution of modern humans enabled much higher levels of innovation, thought experiment, and narrative complexity. In the long run, these yielded a way of life that ultimately led to the demise of Neandertals.

From this model of Neandertal cognition it is possible to generate certain predictions or expectations about the paleoanthropological record. Even though the model is far from comprehensive, it does allow identification of patterns that would be consistent with Neandertal cognition, and patterns that would be inconsistent. It also permits speculation about the evolutionary antecedents of Neandertal cognition.

The Neandertal paleoanthropological record should regularly demonstrate certain characteristics. The first is technical mastery and sophistication. Neandertals would have been fully capable of learning and mastering any basic stone-age technology, including prismatic core technique (indeed, it is quite possible that their level of technical expertise could learn any modern technological activity). Second, Neandertals should demonstrate effective long term adaptations to local environments that included flexibility in the face of shifting conditions. Third, variability in Neandertal material culture should map onto variations in local conditions. Fourth, there should be only a limited amount of technical variability attributable to drift, i.e., small non-directional changes in technique resulting from small errors in intergenerational transmission of technical know how.

On the other hand, the Neandertal paleoanthropological record should not yield evidence of certain other activities. For example, there should be no evidence for long range contingency planning, such as that practiced by native Australians in scheduled burning of specific areas to encourage a second green-up of grass (Lewis, 1982); or evidence for rapid, directional change in technology that results from conscious invention and experimentation; or evidence of long range social networks. Any of these would be outside the scope of expertise based on L-TWM, and would constitute strong evidence against our hypothesis.

Finally, this model of Neandertal cognition provides a basis for speculating about what went before. Given the diffuse neurological storage of long-term memories, one simple prediction is that earlier hominids with a smaller neocortex and smaller association cortices would have had a reduced LTM capacity. One result would be a long-term working memory capable of storing fewer and less sophisticated retrieval structures. This alone would result in less flexibility in expert performance; technology, for example, would be less finely tuned to local circumstances. It is also likely that smaller cortices would be associated with smaller working memory capacities than that of Neandertals, with attendant consequences for complexity of plans of action.

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