

# A COGNITIVE AND NEUROPSYCHOLOGICAL PERSPECTIVE ON THE CHÂTELPERRONIAN

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*Châtelperronian is the term used for a distinctive archaeological assemblage found in areas of southwestern France and northern Spain. Neandertals appear to have been responsible for the artifacts, but some of the artifact types represent a significant change from those used in the previous 200,000 years of Neandertal culture. Two alternative interpretations have been proposed for this change—one emphasizing independent development and the other emphasizing imitation of modern humans. We propose a slightly different scenario in which Neandertals created the artifacts through a form of observational learning known as emulation. This form of learning fits an account of Neandertal thinking that is derived from cognitive models of working memory and long-term working memory and is enriched by examples from neuropsychology.*

CHÂTELPERRONIAN IS THE TERM USED for a distinctive archaeological assemblage found in areas of southwestern France and northern Spain.<sup>1</sup> It is often found stratified above Mousterian industries, and radiocarbon assays date the assemblages to between 42,000 and 32,000 years ago (uncalibrated) (Mellars 1996). The Châtelperronian lithic industry is characterized by a distinctive backed point made on a blade. The technique for producing the blade blanks differed from that used in the contemporary Aurignacian industry. “For cores, the Châtelperronians used large, thick flakes or small blocks and plaquettes which were purposefully shaped by the production of a crest along a smooth, long surface” (d’Errico et al. 1998:s13). Aurignacian knappers used more typical Upper Paleolithic prismatic cores (e.g., d’Errico et al. 1998). Châtelperronian lithic assemblages also included many typical Mousterian elements such as denticulates and sidescrapers, along with endscrapers and burins, which are typical Upper Paleolithic elements (Mellars 1999). Overall, the Châtelperronian lithic elements resemble late Mousterian assemblages to a sufficient degree that most archaeologists accept that the industry’s roots lie in the Mousterian. Corroboration comes from the association of Neandertal fossil remains with Châtelperronian assemblages, the most notable being at the site of Saint-Césaire (Mellars 1999). The Châtelperronian also includes nonlithic elements that are unknown in earlier Mousterian assemblages, in particular bone tools and personal ornaments in the form of pieces of ivory, shell, and bone pierced for hanging (Turk, Dirjec, and

Kavur 1997). Neandertals produced these artifacts themselves, as waste products of the manufacturing process have been found in Châtelperronian sites (d'Errico et al. 1998).

Serious disagreement still exists about the status of the Châtelperronian (Mellars 1996; d'Errico et al. 1998, with comments; Mellars 1999, with comments; Zilhão and d'Errico 1999; d'Errico 2003; Conard and Bolus 2003). Though a majority of archaeologists appear to agree that most or all of the assemblages labeled Châtelperronian are the products of Neandertals and that the industry was geographically restricted to a relatively small area of southwestern France and northern Spain, there is significant disagreement about chronology. Zilhão and d'Errico (1999) argue that many coherent Châtelperronian assemblages clearly antedate the earliest Aurignacian assemblages and challenge all apparent contradictory examples, such as the 38,000–40,000 BP AMS dates for the basal Aurignacian at L'Arbreda and El Costillo, on the basis of stratigraphic, contextual, or typological uncertainties. Mellars (1999) and others argue that sites such as L'Arbreda and El Costillo document the presence of the Aurignacian in northern Spain by 40,000 years ago and that there must have been several thousand years of temporal overlap for the Aurignacian and Châtelperronian.

This disagreement is tangential, but not irrelevant, to our argument. If, as Zilhão and d'Errico maintain, the Châtelperronian everywhere precedes the arrival of people with Aurignacian technology, then all acculturation models would be rendered moot, and the indigenous development of new Châtelperronian activities would provide a fascinating (and unprecedented) case of parallel culture/cognitive development. Our argument takes as one of its premises that Neandertals made the Châtelperronian artifacts and as a second premise that some of the Upper Paleolithic elements of the industry were developed under the influence of Aurignacian people or artifacts. If these premises turn out to be false, then our argument will have little merit. We are primarily concerned with a question that emerges from the acculturation model. Some of the artifacts and techniques that appeared in Châtelperronian assemblages represented new activities with no clear Neandertal antecedents. How did they come to be there, why only these, and what does their presence reveal about Neandertal cognition? What draws us to the Châtelperronian is not a hope that we can help resolve the culture-chronological problems. Instead, we hope to add a cognitive neuropsychological perspective on the nature of this Paleolithic acculturation.

Two theories address the development of the Châtelperronian: acculturation via imitation (e.g., Mellars 1996; Klein 2003) and innovation (e.g., d'Errico et al. 1998). The imitation theory holds that Neandertals observed modern humans, learned how they fashioned these new tools and personal ornaments, and then copied them. A less popular variation on the imitation/acculturation theory is that Neandertals traded or bartered for these tools and ornaments (although this would not explain very well their new living arrangements or manufacturing debris). Innovation theorists posit that Neandertals developed the new artifacts independently as a response to conditions similar to those that led to their development elsewhere or that both Neandertals and modern humans developed

more elaborate symbolic systems as a consequence of contact (d'Errico 2003). The innovation hypothesis is the more provocative of the two. If the new elements of the Châtelperronian were truly an independent innovation on the part of Neandertals, these innovations would most likely have been associated with cognitive changes. After all, Neandertals and their direct ancestors had been producing Mousterian artifacts for at least 200,000 years, and the changes characteristic of the Châtelperronian have no clear antecedents in the local archaeological record. If Neandertals were suddenly innovative, and these innovations had little to do with acculturation, then some biological/cognitive change seems likely to have occurred.

Cognitive archaeologists typically view decorated items and personal ornaments as evidence for symbolic thought, which might further suggest a cognitive change (Nowell 2001; d'Errico et al. 2003). Such a cognitive development might also have been accompanied by changes in language, including expanded grammar and greater syntactical complexity. Verb tenses, including past and future tense uses and the use of the subjunctive mode ("what if" statements), might have flourished, all leading to enhanced reasoning, formal deductive thinking, and greater abstractive ability. However, if these innovations did reflect a greater cognitive ability and, perhaps, greater linguistic flexibility as well, why did Neandertals disappear within, at most, about 10 millennia from the time of their innovations? If, as d'Errico et al. argue, there might have been biological differences between Mousterian Neandertals and Aurignacian modern humans, but not cognitive or cultural differences, and Neandertals were "fully cultured humans" (d'Errico et al. 1998:s22), why—on a geological scale—was their extinction so sudden?

D'Errico et al. do note, however, that if Neandertals obtained modern cultural behaviors through contact with or under the influence of modern humans, no precise mechanisms have yet been proposed to explain this process. This article attempts to do just that: propose a mechanism for the imitation hypothesis, based on a theoretically grounded account of Neandertal cognition. We have previously presented a cognitive model that attempts to explain changes in the archaeological record that have been associated with the evolution of modern humans (Coolidge and Wynn 2001, n.d.). This model is based on the concept of working memory proposed by Baddeley and Hitch (1974) and recent refinements of the model by Baddeley and Logie (1999), Baddeley (2000, 2001), and Kane and Engle (2002).

Working memory is a multiple component system involved in the selection of stimuli deemed relevant to current functioning, their temporary maintenance, the processing and manipulation of the stimuli, and their long-term storage. Our central hypothesis is that an enhancement of working memory capacity distinguished modern cognition from that of archaic humans, including Neandertals. If Neandertals lacked this enhanced capacity, it is likely that they relied almost exclusively on another form of expert cognition known as long-term working memory, one feature of which is the ability to reconstruct complex patterns from minimal cues.

## WORKING MEMORY

In Baddeley's (2001) model, working memory is a form of temporary neural storage that receives inputs from other neural systems and holds them in active attention, thus allowing further processing. It is a system that "holds things in mind," enabling other functions (collectively referred to as "executive functions") such as response inhibition and preparation, resistance to interference, action selection, selective attention, and integration across space and time. Based on experimental results, Baddeley developed a model for working memory that included an attentional panmodal controller, or central executive, and three subsystems: a phonological loop, visuospatial storage, and an episodic buffer. We will define the latter systems first.

Baddeley proposes that the phonological loop accounts for the already substantial empirical evidence for short-term verbal memory. He hypothesizes it has two components—a phonological store that temporarily maintains sounds (most important, speech-based sounds) and an articulatory rehearsal system. Speech sounds within the phonological store are assumed to decay within a few seconds if they are not rehearsed. Through either vocal or subvocal rehearsal (the articulatory rehearsal system), these speech sounds may be maintained or transferred to long-term memory. The visuospatial sketchpad is also a temporary maintenance system, as it holds and maintains visual (e.g., images) and spatial (e.g., relative location) information (see Logie 1995 for an overview of this system).

Both the phonological loop and the visuospatial sketchpad can maintain information in active attention for only a few seconds, after which there is rapid fade, but both also include means of refreshing information through mental rehearsal (e.g., the subvocal articulatory rehearsal one uses when trying to remember lists). While a few seconds may not appear to be much time, it is within this attention window that the mind does its active business, including retrieving information from long-term memory and comparing it to other memory traces and to current perceptions. Within this window, for example, speakers construct sentences and, on the receiving end, recover meaning from words and syntax. Baddeley (2000, 2001) labels this window the episodic buffer. The episodic buffer is thought to serve as an interface between phonological storage, visuospatial storage, and long-term memory. In his view, the episodic buffer increases working memory capacity by being able to integrate scenes and events and to maintain them in meaningful chunks in short-term storage. The recall of helpful retrieval structures from long-term memory binds these thoughts and events into meaningful chunks and gives them their episodic nature (i.e., our conscious awareness of present and past events, our personal and autobiographical memories), and it increases the effective storage capacity of temporary working memory. Baddeley's episodic buffer is the place where the different codes of the phonological loop and the visuospatial sketchpad can be combined into a common code, maintained temporarily for processing (by the executive functions of working memory), and then stored in long-term memory (episodic long-term memory).

Baddeley's working memory model is not without its critics. Rival memory models do typically share his view of multiple subsystems and of temporary and long-term storage based on domain-specific and domain-general codes (see Miyake and Shah 1999 for comprehensive comparisons of various models). Crowder (1993), Cowan (2001), and Ruchkin et al. (n.d.) have proposed contrasting views of Baddeley's short-term memory operations, specifically that activated representations in long-term memory constitute the nature of short-term memory. Baddeley himself (2001) has also provided an overview of the theoretical and empirical challenges to his working memory model.

The terms "attentional panmodal controller," "central executive" (Baddeley 2001), and "executive attention" (Kane and Engle 2002) are essentially synonymous and refer to the central control function of the working memory model. "Executive functions" are the inherent features or abilities under the control of the central executive. Classic executive functions are thought to involve novel and complex problem solving, decision making, planning, and the organization required to complete tasks, which, as we noted earlier, involve response inhibition, preparation, selection, and execution, often in the face of competing but irrelevant stimuli. These functions have numerous sources of evidence associating them with the dorsolateral prefrontal cortex, although certainly not exclusively with that region of the brain. It is also thought that social problem solving and the regulation of social behavior and interactions may further involve the ventromedial prefrontal cortex and the limbic system (for an extended review of frontal lobe systems, see Lichter and Cummings 2001; see Gazzaniga, Ivry, and Mangun 2002 for a more complete discussion of executive functions; see Miyake and Shah 1999 for more complete descriptions of working memory).

Goldberg (2001) has also hinted at the intertwined nature of executive functions and working memory and presents numerous lines of evidence for their common residence in the prefrontal regions of the cortex and their reliance as well upon posterior cortical regions. Kane and Engle (2002) much more strongly state the case for the complex interrelationship of the role of the prefrontal cortex in working memory and executive functions, although they view the latter's chief function to pertain to attention.

We earlier used the term "working memory capacity." The word "capacity" is not used here in the simple sense of storage or size but in the sense of an ability to maintain pertinent information in an active state relevant to goal attainment, especially in the presence of interference. Working memory capacity appears to be a key component of general intelligence (indeed, Kyllonen 1996 equates the two). Working memory capacity also has been shown to be strongly correlated to fluid intelligence, that is, the ability to solve novel problems (Kane and Engle 2002). Thus, any enhancement of working memory capacity should also have profound consequences for virtually all aspects of human thought. Any enhancement of working memory capacity, either through expansion of the attention window of the central executive (Engle, Kane, and Tuholski 1999; Kane and Engle 2002) or expansion of the capacity of the slave subsystems, should have significant consequences for the mind's ability to manipulate information.

Kane and Engle (2002) have strengthened arguments for the self-regulatory nature of working memory, and their extensive empirical studies also strengthen arguments for Baddeley's central executive (although they label it "executive attention"). Barkley (2001) has stressed the role of executive functions in self-regulation from an evolutionary perspective. Much of the early research on executive functions consisted of neuropsychological studies of individuals with brain damage to the frontal lobes, and executive functions were often simply equated with frontal lobe function. More recently, neuroimaging techniques like functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have helped specify the neuronal substrate of working memory and its executive functions (e.g., Koechlin et al. 1999). Gazzaniga, Ivry, and Mangun (2002) now argue that executive functions do not solely reside in a single frontal lobe structure but result from the interplay of diverse cortical and subcortical neural systems, most of which, however, lie in the dorsolateral and ventromedial prefrontal cortices.

We have previously suggested that developments in working memory and its executive functions were critical to the evolution of modern cognition (Coolidge and Wynn 2001, n.d.; Wynn and Coolidge 2003). Three features of enhanced working memory (EWM) capacity led us to grant it priority over other proposed keys to modernity. First, it is of an appropriate magnitude. Individuals without EWM may be only subtly restricted in their general abilities compared with those who possess the trait. For example, they may be able to anticipate future events, have abilities for symbolization, and be able to retrieve and enact complex action sequences from long-term memory. Indeed, most modern activities are performed without EWM (driving to work is an example). However, the expanded attention window of EWM allows more sophisticated contingency planning and innovation through analogy and thought experiment.

Second, working memory and its attendant executive functions appear to be heritable (e.g., Rijdsdijk, Vernon, and Boomsma 2002; Ando, Ono, and Wright 2001; Hansell et al. 2001), with some evidence suggesting that the core of executive functions may be controlled by the additive genetic effect of as few as four gene loci (Coolidge, Thede, and Jang 2004). EWM is not the result of a massive reorganization of the brain; instead, we are proposing that it was a relatively modest neuronal redevelopment that had profound consequences. It appears then that it is an almost perfect candidate for Mithen's (1996) and Klein and Edgar's (2002) hypotheses that a relatively simple, but profound, mutation led to modern human thinking.

Third, EWM has provocative implications for language. If, as we have proposed, EWM specifically occurred through an expanded phonological storage capacity, the result may have been a flowering of tenses and an enhanced ability to generate and understand longer utterances. Baddeley (2001) has recently noted the critical importance of phonological storage in the evolution of language and in the executive control of actions, particularly in switching attention to novel and goal-relevant stimuli. Indeed, Baddeley and Logie (1999) have called phonological storage the "bottleneck" for all language comprehension (and we, by extension,

would see it as a bottleneck for speech production as well). Neuropsychological evidence for the importance of the phonological loop in the acquisition of language comes from studies of children with and without specific language impairments. In children without language impairments, Gathercole and Baddeley (1989) found that the capacity to repeat unfamiliar pseudowords was significantly correlated with level of vocabulary development. Children with a specific language impairment (SLI), but normal nonverbal intelligence, have been shown to be particularly impaired in pseudoword repetition, even beyond what would be predicted by their SLI. Interestingly, Bishop, North, and Donlan (1996) found phonological storage, as measured by pseudoword repetition, was highly heritable.

Finally, an expanded attention window and ability to “hold things in mind” probably enabled the creation of more complex narrative structures, which have a clear role in communication of information, which, in turn, may have enhanced reproductive fitness (Sugiyama 2001). This position is still completely consonant with the idea that some symbolism capacity and simple grammar were likely to be components of archaic human communication.

### **EXPERT PERFORMANCE AND NEANDERTAL COGNITION**

Where does a non-enhanced or archaic working memory model leave Neandertals? One way to describe Neandertal cognition is by reference to modern human thinking with a single piece missing. This piece was, we suggest, the enhancement of working memory capacity, either in its non-domain-specific general capacity or through increased capacity of the phonological loop. Such a missing piece might have limited Neandertals’ speech comprehension and production capacity. Thus, Neandertals may have lacked fully modern speech syntax with tense and embedding, extended narrative, and algorithmic thought. These may strike one as crippling deficits, but they are not. Everything else that is true of modern cognition may have been in place, including expert performance. Mithen (1996) previously suggested that without cognitive fluidity, Neandertals may have had a consciousness akin to Dennett’s (1991) example of the nature of consciousness while driving to work, that is, rolling consciousness with swift memory loss.

These proposed subtle, yet profound, differences in working memory capacity, leaving Neandertals with archaic or non-enhanced working memory, would not have left them bereft of general intelligence or language ability (e.g., Hayden 1993). In fact, we and many others have argued that they possessed skilled cognitive abilities, especially with regard to the production of relatively sophisticated stone tools, and they managed to survive for over 200,000 years in varied, often harsh, and changing climates (e.g., Trinkaus and Shipman 1993; White 2001). However, their stone tools were not highly innovative; indeed, the range of tool types and knapping techniques remained virtually unchanged for approximately 200 millennia until the appearance of the Châtelperronian. Yes, there were regional differences among Middle Paleolithic industries—indeed, the Middle Paleolithic may have had greater regional variability than the succeeding

Aurignacian—and new tool types did occasionally appear; but this situation was nothing like the comparatively rapid changes in technology and artifact style that characterized Upper Paleolithic industries.

If our supposition is correct, that a non-enhanced working memory capacity and its attendant executive functions characterized Neandertal cognition, then what specific cognitive ability underpins the Châtelperronian imitations? Our proposed solution to this puzzle is based on two lines of evidence—archaeological evidence for expert, skilled cognition and neuropsychological evidence presented by Lhermitte (1983) and colleagues (Lhermitte, Pillon, and Serdaru 1986) for the role of the ventromedial prefrontal cortex in imitative behavior.

As important as enhanced executive functions are to modern life, they are not the medium of most modern thinking. Much of what we do and think about consists of “taken for granted knowledge,” to use Polanyi’s (1967) terms. These are schemata encoded into long-term memory and activated easily with minimal on-line processing by working memory. They are learned relatively slowly, reinforced often, and are fully capable of directing most human action. In cases of expert activity, this skilled cognition can become very impressive indeed, deploying pattern recognition schemes and procedural memory schemata that achieve complex results. But working memory plays only a small role in execution; the classic “driving to work” scenario indicates that these skilled cognitive tasks can bypass working memory entirely. Expert cognition is not a primitive form of thinking; indeed, many of our finest achievements are the product of expert, skilled cognition (playing the piano, building a cabinet, etc.). But expert cognition lacks the dynamic, on-the-spot problem solving that is enabled by enhanced working memory. We suggest that expert, skilled cognition was the hallmark of Neandertal thinking (and, very likely, that of all archaic *Homo sapiens*).

Our characterization of Neandertals’ expert cognition is derived from Ericsson, Krampe, and Tesch-Romer’s (1993) experimental research on expert performance and Keller and Keller’s (1996) ethnographic account of blacksmithing. Ericsson and colleagues studied expert performance by training subjects to become very good at remembering spans of digits and thereby discovered that individuals developed tricks for rapidly encoding the digits into long-term memory (LTM). These tricks involved clumping digits and associating the sequence with some familiar pattern already held in LTM. The mnemonics and rehearsal strategies typical of short-term memory either were not used or were used only for the last digit strings. Similarly, chess masters associated perceived patterns with patterns learned over years and held in LTM. The key to this kind of expert cognition appears to be employing techniques for rapid encoding and retrieval of task-relevant information in LTM. Associating with previously encoded patterns is one such technique, so that the more one knows, the more rapidly one can encode and retrieve task-relevant information. Ericsson terms coordinated sets of retrieval cues “retrieval structures” and considers them the key component of expert performance. On a commonsense level, this is clearly what experts do, but it is not much like working memory.

The efficacy of expert cognition is obvious in chess masters, but it is also the



primary cognition of skilled technical activity. Keller and Keller (1996) studied blacksmithing as observers and participants, and their account is similar to that of Ericsson and colleagues. When a smith approaches a particular task, he or she first assesses what is needed through a complex of associated images that Keller and Keller term an umbrella plan. These images are task relevant and include associations of tools, raw materials, time, anticipated quality of product, profit, and so on. For expert smiths, these umbrella plans are largely nonverbal (though they can be described if prompted) and are based on retrieval of relevant information from LTM. During actual forging, the smith guides his or her actions with “constellations” that are similarly constituted through association of images, but which are tied to a specific step in the technological process. Perceptions of the task, including heat, color, and tactile awareness, are guided largely by learned schemes from LTM. These perceptions are not inflexible—indeed, completion depends on flexibility—but they are flexible only within the parameters of LTM schemes that already exist (and were learned laboriously).

A telling similarity between blacksmithing, chess, and any expert activity is the time necessary to achieve mastery—ten years (Ericsson and Kintsch 1995). Another similarity is the relative unimportance of true working memory. Working memory is little engaged, or not at all, especially when tasks have become routine. Indeed, a recent fMRI study of chess players showed a surprising paucity of activation of the prefrontal and frontal cortices (Atherton et al. 2003). Few would question the complexity of chess or the general cognitive ability required for its successful playing. However, these results appear to demonstrate that chess is primarily a skilled spatial cognition. Because the fMRI showed strong parietal lobe activation during chess playing, Atherton and colleagues speculated that playing chess involves more complex spatial computation than just spatial and visual processing and that it includes the integration of incoming spatial information with previously stored knowledge.

We suggest that expert cognition was the hallmark of Neandertal thinking and that it can account for just about everything that we know about Neandertals from the archaeological record. Neandertal stone knappers, for example, were as adept as any in the modern world. Knapping techniques such as Levallois or the flake-blade technique of the African Middle Stone Age have long been used as temporal and cultural markers and have been associated with Neandertals and African archaic *Homo sapiens*, respectively. The complexity of Levallois has long been a focus of European Paleolithic specialists, and we now have a comprehensive understanding of the steps necessary for the production of Levallois flakes and blades (Boeda 1995; Chazan 1997; Van Peer 1992). The complexity of this task in terms of number of steps and the required flexibility of decision chains is truly impressive. Schlinger’s (1996) analysis of a single refitted Levallois core from Maastricht-Belvédère is most enlightening. The knapper produced a number of Levallois flakes from a single mass of flint. In each successive task, he or she had to modify the steps of core preparation in order to produce a similarly sized and shaped flake each time.

More generally, when Neandertals were presented with a knapping task,

features of the goal and available materials (raw material, hammers, intended function, time available, etc.) would have acted as cues for appropriate retrieval structures held in long-term memory. These retrieval structures consisted largely of procedural memories, visual and aural images, and perhaps also declarative knowledge in the form of words. The number and variety of retrieval structures allowed great flexibility in execution, but only within the range of known solutions. The variety of Levallois techniques (preferential, recurrent, bi-directional, etc.; Chazan 1997) attests to the flexibility of Neandertal retrieval structures. Because retrieval structures are held in long-term memory, they are not inherently innovative. The retrieval structures also enable rapid encoding of new information, if any, derived from the task. Neandertal knapping was not rote application of technique but the flexible application of a constellation, to use the Kellers' (1996) term—just what we would expect from skilled craftsmen. Levallois represents the acme of stone knapping that is unsurpassed in the repertoire of even modern knappers. Unfortunately, prismatic blade technique has often been assigned this status simply because it is *generally* (but far from only or always) associated with modern humans. However, the complexity of prismatic core techniques is actually less than that of Levallois in terms of the number and interrelation of intermediate steps. Yes, it makes more efficient use of raw material, but this does not bear on the technical complexity of the task itself.

Neandertal foraging was also skilled but did not rely on managed plans (Wynn and Coolidge 2003). The archaeological record indicates that Neandertals were capable of hunting large mammals such as horses (e.g., at La Quina) and bison (e.g., at Coudoulous and Mauran) (Mellars 1996). Their primary technique appears to have involved the use of (sometimes stone-tipped) spears (Kuhn 1995) with close-in killing. Berger and Trinkaus (1995) have compared the postcranial trauma patterns of Neandertals to those of rodeo athletes and conclude 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, if not entirely, opportunistic. There is little or no evidence for the kind of managed hunting (e.g., selective killing of young males) or specialized hunting (mass kills of single species with storage of meat) that appears late in the Paleolithic record. In managed foraging, people make cost-benefit judgments about the timing of activities and trade-offs in resources, and they often modify landscapes for future use (Wynn and Coolidge 2003). Neandertals hunted what was available and almost certainly could be selective when appropriate (Gaudzinski and Roebroeks 2000). They were very successful hunters, indeed good enough to flourish in a relatively hostile European glacial environment, but they did not “tweak the system” by using managed approaches (Wynn and Coolidge 2003). This behavior is all consistent with expert knowledge and culture.

The expert culture model for Neandertals also makes sense of some of the

puzzles of the paleoanthropological record. The first is the coexistence of Neandertals and modern humans, apparently for several thousand years. This situation suggests that modern human culture was not immediately more successful and did not dominate that of Neandertals. Indeed, the evidence suggests that modern humans may have abandoned the Near East when Neandertals appeared there after 100,000 years ago (Arsuaga 2002; Shea 2003). All this attests to the effectiveness of Neandertals' expert culture. Expert knowledge is acquired slowly, even in the modern world, and a society based on expert knowledge would value the skills of individuals. These are the masters from whom apprentices learn, and they can be effective teachers even after their motor abilities have declined. Older, skilled individuals would have played important roles in Neandertal society, so it is not surprising that we find their remains in the paleoanthropological record. Expert performance presumes that Neandertals had some oral language, but oral language is a minor player in the learning of skill even today, and modern syntax is not necessary.

Modern human culture is also largely a culture of skill, but with the important addition of modern syntax and algorithms. Ultimately, this addition may have allowed for innovations against which Neandertals could not compete. What Neandertal culture lacked was habitual innovation, in the sense of the regular creation and deployment of novel solutions. Skilled schemata are flexible within the parameters of a particular task or set of tasks, but they are slow to change. Moreover, because Neandertals may have had a somewhat more restricted working memory capacity, they may not have been able to "hold in mind" the disparate content necessary for effective use of analogy, and they may not have been able to perform the kind of mental rehearsal and thought experimentation (Shepard 1997) necessary for effective innovation. Neandertal culture was simply not innovative (e.g., Mellars 1999), and as successful as it clearly was, this lack eventually led to its demise.

## EMULATION

This model of Neandertal cognition helps us understand the nature of the information transfer evident in Châtelperronian assemblages. Archaeologists who advocate imitation as the root of the Châtelperronian-Aurignacian similarities appear only to mean "learned from" rather than any of the more detailed definitions available from the comparative literature. For an example of observational learning to qualify as true imitation, it must include copying at least part of a specific motor sequence (Whiten and Ham 1992; Tomasello et al. 1987; Tomasello 1994; Whiten 2000). However, features of the Châtelperronian artifacts themselves suggest that true imitation was not the form of social learning Neandertals used to acquire these new behaviors. D'Errico and colleagues emphasize that the blades in Châtelperronian assemblages were produced by a technique slightly different from that typical of the Aurignacian: "For cores, the Châtelperronians used large, thick flakes or small blocks and plaquettes which were purposefully shaped by the production of a crest along a smooth, long surface" (d'Errico et al. 1998:s13). This

description reminds us of some of the cues true of Levallois retrieval structures; had the Châtelperronian knappers copied the actions of Aurignacian knappers, we would expect to see prismatic cores. To reiterate a point made earlier, prismatic blade techniques are not inherently more complex than Levallois techniques, and there is no reason to believe that Neandertal knappers could not have easily acquired the technique. (After all, they had done so before at several times and places; e.g., Bar-Yosef and Kuhn 1999; Conard 1990). It seems unlikely, therefore, that Neandertals observed Aurignacian knapping. So how then could they have acquired blade technology? More likely, it was through reconstructing the procedure based on examination of the finished products. This form of social learning is termed "emulation."

Emulation is a form of observational learning in which the subject understands the goal but applies his or her own procedure for achieving it (Whiten and Ham 1992; Tomasello et al. 1987; Tomasello 1994; Byrne and Russon 1998). The goal must be familiar and recognizable. "How the observer reaches that goal is a matter of individual learning and prior knowledge" (Byrne and Russon 1998:669). Byrne and Russon argue that emulation is a kind of learning based on "priming." From a cognitive perspective, priming increases "the activation of stored internal representations that correspond to those particular environmental stimuli. . . . The concept of priming assumes that there exist structures ('records') in memory that represent familiar or identifiable items" (Byrne and Russon 1998:669). Neandertal knapping expertise was based on a huge array of retrieval structures held in long-term memory; these retrieval structures were clearly "stored internal representations" that could be deployed in emulation. Observing an Aurignacian blade would have "primed" these structures, leading to a set of procedures for achieving that goal. 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 emulation could have produced all of the modern elements we see in Châtelperronian culture without the necessity of invoking instruction or direct observation of the procedure. D'Errico and colleagues have argued that "late Neandertals perforated teeth using techniques different from those used by Aurignacian AMH" (d'Errico et al. 2003:22) and that "the Châtelperronian awls show a more varied repertoire of blank types (e.g., use of carnivore-fibulae and massive epiphyseal fragments obtained through fracture), methods of blank production, and degrees of shaping" (d'Errico et al. 2003:24). They propose that this situation is evidence for independent invention; but it is also exactly what one would expect from emulation. In other words, it is not necessary that Neandertals ever directly observed modern human knapping or bead making; they could have reconstructed the procedures by observing the artifacts and debitage alone. Indeed, the nature of Châtelperronian artifacts suggests that Neandertals rarely, if ever, directly observed modern human techniques. Given the sophistication of their own

knapping and motor abilities and their retrieval structures, they almost certainly would have been able to reproduce prismatic core techniques precisely if they had actually observed the procedure.

A second line of reasoning supporting the “emulation” hypothesis follows neuropsychological evidence from studies of brain-damaged patients. As noted earlier, the prefrontal cortex plays a dominant role in the active maintenance of information critical to action selection and goal attainment. One aspect of action selection is based upon environmental and social context cues, which, it will be recalled, are also central to long-term working memory. While both the dorsolateral and ventromedial prefrontal cortices are ultimately involved in the selection and execution of an action, the ventromedial prefrontal cortex may be more involved in social decision making (e.g., Gazzaniga, Ivry, and Mangun 2002). Patients with damage to these latter neural pathways have been shown to be overly dependent upon perceptual and environmental cues and less dependent upon social cues. Lhermitte (1983) and colleagues (Lhermitte, Pillon, and Serdaru 1986) placed patients with ventromedial prefrontal damage in social situations with strong environmental cues for highly inappropriate behavior. For example, a patient would be asked to come to a hospital office, and on a table in front of the office door would be a hammer, nail, and picture. These patients would invariably respond to these cues by hanging up the picture.

Through this and other social paradigms (including leaving a hypodermic needle on his desk and bending over in front of the patient!), Lhermitte created the terms “utilization behavior” or “environmental dependency syndrome” to describe these patients’ tendency to be highly dependent upon perceptual and environmental cues for the selection of their behavior, regardless of the social inappropriateness of that behavior. Interestingly also, the patients did not question or challenge Lhermitte’s unusual behavior. In addition, Lhermitte showed that these patients are also overly prone to imitate their doctor’s behavior, again without regard for whether the behavior was combing one’s hair or thumbing one’s nose. These results reinforce experimental evidence that frontal lobe functions mediate action selection for modern humans, but they also highlight the organizational power of retrieval structures held in long-term memory.

If, as we propose, Neandertals reproduced modern human artifacts by emulation, rather than true imitation, there must have been little direct interaction between the them and modern humans. Direct instruction or trade appears to have been very unlikely. Instead, a model of rare or remote contact is more plausible, one in which Neandertals either observed modern humans from a distance, observed abandoned sites and artifacts, or both.

## CONCLUSIONS

As noted previously, empirical evidence is strong for the relationship between working memory capacity and intelligence (e.g., Kyllonen 1966; Kane and Engel 2002). Horn and Cattell (1966) proposed an influential general intelligence dichotomy of crystallized intelligence versus fluid intelligence. They stated that

crystallized intelligence involved the knowledge of formal aspects of culture, usually obtained through formal schooling. They hypothesized that fluid intelligence was an ability to solve new problems, where neither schooling nor acculturation would facilitate task performance. Kane and Engle (2002) have empirically demonstrated the strong relationship of many measures of working memory capacity to fluid intelligence measures (such as Raven's Progressive Matrices or Cattell's Culture Fair Test).

We are not proposing radical differences in cognition between Neandertals and modern humans at the time of the Châtelperronian culture. However, a mutation may have enhanced the working memory capacity of modern humans beyond that of Neandertals (indeed, even beyond the working memory capacity of archaic humans), resulting in greater fluid intelligence for the modern humans and an exceptional ability to solve new problems associated with increasing population density (competition for resources) and a changing climate. Neandertals undoubtedly had working memory, just not expanded or enhanced working memory. Interestingly, it may be no mere coincidence that Mithen (1996) proposed that Neandertals lacked a cognitive "fluidity" that prevented a full integration of specialized skills and sources of knowledge, while we have noted the evidence for the relationship between working memory capacity and "fluid" intelligence. Furthermore, his timeframe for a neural mutation, which he calls the final step to full cognitive fluidity, is between 60,000 and 30,000 years ago.

Thus, we arrive at the crux of our neuropsychological solution to the Châtelperronian puzzle. Perhaps, with a non-enhanced (archaic) working memory capacity, these expert Neandertal stone knappers were overly dependent upon the environmental cues presented to them by the Aurignacian culture: a well-prepared core, a hammerstone, and numerous examples of final or semi-final products strewn about. This scenario would not even require a direct interaction between Neandertals and modern humans. Neandertals might have surreptitiously observed modern humans in action or visited these production sites long after modern humans had left. Because they had expert cognition, Neandertals could have easily reconstructed the entire knapping technology from examination of the discarded cores and debitage. All of the perceptual cues would have been in place to allow them to "reverse engineer" the procedure. With manual dexterity no different than that of modern humans (Niewoehner et al. 2003), they might have easily accomplished this process. Furthermore, hybridization hypotheses between Neandertals and modern humans as an explanation for the Châtelperronian tradition have been weakened by Klein's (2003) recent evidence against such hybridization.

Our proposed scenario allows us to propose some testable hypotheses. We would expect that archaeologists should be able to find other examples of Neandertal emulation (or emulation by other archaic humans). These would consist of items that operate in domains of activity for which Neandertals already had expertise, e.g., knapping, hafting, shaping bone, use of pigments, etc. However, once emulated, these items would not change much because of the inherently non-innovative nature of expertise. They would simply enter

Neandertal stocks of knowledge to be tapped when appropriate.

We would not, however, expect certain abstract items to be emulated by Neandertals. For example, we would not expect Neandertals to emulate the computational devices (notched bones that were tally sticks of some kind) found in some Aurignacian and Gravettian sites or to emulate systems of abstract symbols, such as the one implied by the Hohlenstein-Stadel lion-headed man. Indeed, we predict that Neandertal sites, of whatever age, will never yield evidence for computational systems, stylistic change (in the sense of the emergence, popularity, and decline of stylistic elements), true managed foraging (in which Neandertals used well-timed seasonal scheduling, or herd culling, or food production), or long-distance navigation over water. All of these depend on enhanced working memory.

We would expect that Neandertal sites might well yield evidence of high levels of expertise in stone knapping, of effective tactical hunting (including killing dangerous animals and a focus on single species), and of many variations on basic themes (e.g., a range of shapes for *Blattspitzen* [foliate points]) and perhaps even evidence for some individuals having been valued experts (e.g., special artifacts included in burials).

In summary, in spite of their similarities, there were cultural differences between Neandertals and modern humans. Parietal art, highly ornate burial practices, land-use planning, and evidence for strategic social alliances all became common in the archaeological record of modern humans by 30,000 years ago (Gamble 1999). A number of current theories propose a mutation in the brain that produced a rewiring of neural pathways (e.g., Coolidge and Wynn 2001; Klein and Edgar 2002; Mithen 1996; Ambrose 2001). Our specific hypothesis is that an increase in the capacity of working memory was a critical development that led to the modern human mind. Through emulation, the expert minds of Neandertals were able to reproduce many aspects of Upper Paleolithic material culture, but, even though they competed successfully for thousands of years, the Neandertals eventually lost out to the innovative mind and culture of *Homo sapiens sapiens*.

#### NOTE

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