

Accepted Manuscript

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PII: S0047-2484(07)00020-6
DOI: [10.1016/j.jhevol.2007.01.003](https://doi.org/10.1016/j.jhevol.2007.01.003)
Reference: YJHEV 1013

To appear in: *Journal of Human Evolution*

Received Date: 27 November 2006
Revised Date: 17 January 2007
Accepted Date: 17 January 2007

Please cite this article as: Coolidge, F.L., Wynn, T. The working memory account of Neandertal cognition—how phonological storage capacity may be related to recursion and the pragmatics of modern speech, *Journal of Human Evolution* (2007), doi: [10.1016/j.jhevol.2007.01.003](https://doi.org/10.1016/j.jhevol.2007.01.003)

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The working memory account of Neandertal cognition— how phonological storage capacity may be related to recursion and the pragmatics of modern speech

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Keywords: Working memory; Phonological storage; Recursion; Speech act; Subjunctive mode of speech

Beaman (2007) criticizes our arguments for the importance of phonological storage capacity (PSC) in accounting for purported cognitive differences between Neandertals and *Homo sapiens* (Wynn and Coolidge, 2003, 2004; Coolidge and Wynn, 2004, 2005). His criticism has two components. First, Beaman contends that we have misinterpreted Baddeley's (2001) thinking on the role of the phonological loop as a bottleneck to speech production and comprehension. Second, Beaman argues that we have misinterpreted the neuropsychological evidence for the consequences of short-term-memory loss in brain-damaged patients. Before we defend our initial contention concerning the possible significance of PSC in the evolution of enhanced working memory, we feel that it is important to remind readers of the original context of the argument. Our primary goal in "The expert Neandertal mind" (Wynn and Coolidge, 2004) was to describe features of Neandertal cognition, not just to defend a specific model of working memory enhancement.

With regard to the misinterpretation of Baddeley's original supposition, Beaman (2007) may also have misinterpreted Baddeley's scientific intentions. Had Baddeley thought that the "major bottleneck for language comprehension" hypothesis was worthless, it is unlikely that he would have written that "the phonological loop might reasonably be considered to form a major bottleneck in the process of spoken language comprehension" (Baddeley and Logie, 1999: 41). In a later publication (Baddeley, 2001), he reemphasized the importance of the evolutionary function of the phonological loop in the acquisition of language. Obviously, he thought the idea had some merit, at least theoretically. However, as Beaman points out, Baddeley and Logie did weaken their own supposition by citing empirical evidence from studies of brain-damaged patients. Sole reliance on evidence from brain-damaged patients is a treacherous form of argument. We have previously (Wynn and Coolidge, 2004) noted the problems inherent in

assuming that the behavioral sequelae of brain damage are the same as the sequelae of restricted working memory or limited working memory. Beaman's critique is overwhelmingly based on such studies. We specifically note the obvious: brain damage is not randomly assigned to people or to brain areas. Head injury, which is often the most prevalent type of brain damage, and most commonly studied, results in notoriously diffuse focal sites. In addition, brain damage in similar areas in two patients may result in different patterns of neuropsychological dysfunction or may have no functional significance for some patients. Furthermore, if the phonological analysis and storage capacity of the type of patients Beaman cites had damage in these areas, some might be virtually untestable. From the studies he cites, their ability to understand instructions for tasks and their recall of long-term memories strongly suggests that their inner speech and articulatory abilities are not impaired, and thus, any suppositions about the relationship of the phonological store to long-term memory may be suspect, in our opinion. We have preferred to make our inferences based on individual differences in non-brain-damaged samples, although we do not deny or denigrate the value of the latter source of data. Our review of mostly nonclinical studies strongly supports our contention that, indeed, PSC is a major bottleneck for language comprehension and production (e.g., Adams and Gathercole, 2000; Aboitiz et al., 2006; Gathercole et al., 2004; Kane and Engle, 2000, 2002).

Beaman (2007) also declines to address our enhanced working memory model and its interrelationships to PSC and executive control. In part, he declines because he states that it is "less susceptible to test" (Beaman, 2007: XXX). However, we have reviewed numerous studies, almost entirely based on normal subjects, which demonstrate the strong relationship existing among various measures of working memory capacity, executive control, and PSC with general intelligence and fluid intelligence (i.e., novel problem solving; Kane and Engle, 2002). Adults

who have greater PSC have also been found to score higher on verbal tests of intelligence (indeed, digit span is a subtest of the Wechsler Adult Intelligence Scale, although, admittedly, it has one of the weakest correlations with full-scale IQ among the subtests) and higher on measures of verbal fluency; they also do better on retroactive and proactive interference tasks (Kane and Engle, 2002). In normal children who are matched on nonverbal intelligence measures, those with greater PSC had a larger vocabulary, produced longer utterances, and demonstrated a greater range of syntactic construction (Adams and Gathercole, 2000). The latter finding does not rule out the influence of the effect of a greater general working memory capacity or the influence of some other factor or factors. Again, however, taken on the whole, we believe that these findings tend to support Baddeley's tentative contention that PSC may have evolved primarily for the acquisition of language, and we think the evidence lends supports for his bottleneck hypothesis.

In the latter part of his comment, Beaman (2007: XXX) notes that "there are no reports in the literature of impairments to self-reflection, introspection, or long-term storage reliably occurring among short-term-memory patients." Beaman fails to see how the PSC or the articulatory loop could affect self-reflection or introspection. As this is a key to our argument, we clarify and expand upon these possible interrelationships below.

In a seminal article, Hauser et al. (2002) proposed a distinction between the faculty of language in the broad sense (FLB) and the narrow sense (FLN). FLN, unique to humans, refers to an abstract linguistic computational system alone, which was proposed to be independent of other systems such as memory. FLN is "a computational system (narrow syntax) [that] generates internal representations and maps them into the sensory-motor interface by the phonological system, and into the conceptual-intentional interface by the (formal) semantic system" (Hauser et

al., 2002: 1571). Hauser et al. also claimed that a core property of FLN, and unique only to human language, is recursion (that is, embedding a phrase within a phrase, for example:

Hermione said that Hagrid wants to see you).

Recursion, as noted by Hauser et al. (2002), relies upon the phonological storage system, and the crux of the first part of our present argument is that recursion required greater PSC. Recursion may, theoretically at least, be infinitely generative, but it is obviously limited by PSC. Recently, Aboitiz et al. (2006) noted that PSC represents a short-term-memory ensemble that can be phylogenetically tracked to earlier homologues in hominid evolution and to current primate brain systems. Further, they postulate that language has evolved primarily through the expansion of short-term-memory capacity, “which has allowed the processing of sounds, conveying elaborate meanings and eventually participating in syntactic processes.” (Aboitiz et al., 2006: 41). They thought that an expanding memory system allowed more complex memories representing multiple items to be combinatorially manipulated, which they believe to be the equivalent to Hauser et al.’s syntactic recursion. Such linguistic recursion would demand significant working memory resources, which we think is the equivalent of our concept of enhanced working memory (e.g., Coolidge and Wynn, 2005).

Aboitiz et al. (2006) also noted that empirical studies of short and long sentences appear to reveal that short sentences do not impose an inordinate load on working memory capacity or short-term-memory systems, which may have particular relevance to Neandertal cognition. However, longer canonical sentences, particularly those that present objects of the action first, rather than subjects of the action, do impose a significantly greater load upon general working memory capacity and its phonological subsystem than nonrecursive and subject-first sentences. Indeed, Beaman cites brain-damage studies that demonstrate that complex, long-embedded

sentences require surface forms that must be retained verbatim in order to be successfully recalled later.

Perhaps the simplest interpretation of the effect enhanced working memory may have had on linguistic communication is that it enlarged the recursive capacity of language. An enhancement of working memory would yield immediate results in the length and complexity of sentences, thus accounting for the claims of those who emphasize oral language and oral traditions as characteristic of modern culture (Arsuaga, 2001; Donald, 1997; Hodgson and Helvenston, 2006; Sugiyama, 2001). Arsuaga (2001) specifically argued that Cro-Magnon's Aurignacian culture was made very effective by the ability to share myths that linked them both to the natural world and their ancestors. A release from simple morphemic declarative sentences would have been made possible by enhanced working memory, and perhaps, greater PSC would have enhanced this myth-sharing ability. Sugiyama (2001) has speculated that narratives are excellent substitutes for time-consuming and sometimes dangerous first-hand experience. She also posited that fitness in varying habitats may have particularly aided foraging knowledge by transmitting information through narratives about geography, plants, fauna, weather, and other aspects of the environment.

However, those who advance recursion as the key to modern language and consequently modern thinking, such as Hauser et al. (2002), fail to conjecture exactly how recursion accomplishes its magic. Even other advocates of recursion as the key to modern thinking, such as Aboitiz et al. (2006), who have posited that recursion is highly dependent upon PSC, also neglect to explicate the specific advantages and mechanisms of recursion other than noting that it limits syntactical processing. To our minds, the questions become: What is the relationship of recursion

to modern language and thinking? And, what might be the mechanism or subspecies of recursion that bestows its advantages to cognition?

One possibility is that recursion influenced the nature of speech acts or the pragmatics of speech. A speech act refers to the act that is done or performed by speaking (e.g., Adams, 2002). There is far from a general consensus on a single taxonomy assessing the intent of communication, although speech act analyses typically measure exclamatives (shouts of pain, pleasure, or surprise), imperatives (commands), declaratives (statements of fact, greetings, denials), and interrogatives [questions or requests; see Adams (2002) and Cruse (2000) for more complete reviews].

Our argument draws on the characteristics of the illocutionary force of a speech act as proposed by Cruse (2000). Cruse noted that utterances may have forms without explicit performative verbs, and his categorization was self-admittedly nonexhaustive. However, all four of his proposed categories are common to most previous speech act taxonomies: exclamatives, imperatives, declaratives, and interrogatives. The subjunctive mode of speech, which is often neglected in speech act taxonomies or only sometimes included as a type of declarative statement, expresses subjective statements, such as wishes, possibilities, and statements that are contrary to facts. We are hypothesizing that recursion was a necessary condition for subjunctive speech acts. Thus, it was not the length of an utterance, per se, or recursion, per se, that was evolutionarily advantageous, but recursion allowed the formation and release of subjunctive thinking. Recursion, itself, as noted by Hauser et al. (2002), relies upon the phonological storage system, and we propose that recursion relies heavily upon an enhanced or expanded PSC.

We postulate that enhanced working memory, by way of recursion, may have allowed the speaker to “hold in mind” a much greater number of options, and as such, given the speaker a

greater range of behavioral flexibility and even creativity. We have previously hypothesized (Coolidge and Wynn, 2005) that the ability to reflect upon a greater number of options allows the organism not only a choice among those options (based in part on previous successes or failures of each option) but also the ability to choose a future option or actively create an alternative plan of action. Thus it is possible that the “what if” capability of the subjunctive mode of speech could only be expressed through recursion, and recursive speech may have arisen as a function of enhanced working memory. Interesting support for this latter hypothesis comes from a study (Everett, 2005) of an Amazonian tribe that appears (we are aware that it is a controversial claim) to lack recursion in their language, *Pirahã*. Everett also found that another lacuna in the *Pirahã* language was the ability to refer to the ancient past or the distant future. Their language also lacked creation myths, references to nonliving relatives, abstract concepts, or references to distant places.

We propose that the subjunctive mode of speech may also have aided the rapid evolution of culture through “thought experiments.” Shepard (1997) thought that the mere accumulation of facts [as in Baddeley’s semantic memory or Mithen’s (1996) natural history intelligence or technical intelligence] would not result in advances in scientific human knowledge, but that its advancement would require thought experiments. He postulated that every real experiment might have been preceded by thought experiments 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 a central executive and replete with the executive function metaphors. For example, he viewed consciousness as the culmination of an evolutionary trend where consciousness served as an executive decision-maker with an acquired ability to predict the

future and act on those hypothetical constructions. This view is entirely consonant with our concept of enhanced working memory.

The subjunctive mode of speech might also have been one basis for therianthropic art, one of the more impressive products of Aurignacian culture. Certainly, monsters and therianthropes would have lurked in dreams of *Homo habilis*, *Homo erectus*, and Neandertals. However, it may have taken truly modern minds, with a full complement of speech acts like the subjunctive, to turn those monsters into tangible icons.

One other recent piece of evidence helps support this tentative coalition of enhanced working memory, increased PSC, the development of recursive thinking and speech, and the use of the subjunctive pragmatic of speech. Despite what has been historically assumed, allometric analyses suggest that the frontal lobes have undergone evolutionary inertia within Hominoidea (Semendeferi et al., 2002). Bruner's (2004) recent allometric analyses support this frontal lobe stasis, particularly between Neandertals and modern *H. sapiens*. Certainly, the evolution of the genus *Homo* has been associated with greater cranial capacity, increasing encephalization, and frontal widening. The allometric trajectory that best distinguished anatomically modern *H. sapiens* and Neandertals was a tendency towards klinorhynchity or globularity in modern humans (Bruner et al., 2003). Bruner (2004) speculated that the sequela of globularity might have been greater interconnectivity between the major lobes of the brain, and an expansion of the parietal lobes, especially inferiorly. The inferior parietal lobes, particularly the supramarginal and angular gyri, play major roles in PSC and in subvocal articulatory processing (i.e., inner speech). Furthermore, Carruthers (2002) noted the important role that inner speech plays in intermodular thinking (i.e., making visual and spatial representations more accessible to cognitive processing). Bruner (2004) further speculated that considering the role of the parietal lobes in visuospatial

integration and the role that the inferior parietal lobes play in making this information accessible to language, and thus to the recognition and communication of the external environment, these parietal lobe structures “may be directly related to the evolution of such ‘inner reality’” (p. 300).

In summary, recursion is said to be the hallmark of modern language. From the evidence we have reviewed, we assert that recursion may not only have required greater working memory capacity but it may have also required greater PSC. We believe that a genetic neural mutation, sometime within the last 100,000 years, enhanced working memory capacity and/or PSC. The sequela of the latter change may have allowed recursive and canonical utterances. We propose that recursive embedding may have allowed subjunctive speech acts, which in turn may have given rise to symbolism and perhaps even enabled therianthropic art (Coolidge and Wynn, 2006). Subjunctive speech acts may have also given rise to thought experiments and simulation, free of the inherent dangers of actual trial-and-error. Finally, a full complement of speech acts may have allowed the creation of a more accurate “inner reality” of the external environment and successful anticipations of others’ behavior (i.e., theory of mind), and a more accurate picture of external realities was clearly evolutionarily advantageous. This inner reality undoubtedly is heavily involved in Beaman’s (2007) questions about PSC, self-reflection, and introspection. Indeed, Beaman (2007) at the end of his comment is correct: Cross-disciplinary theorizing regarding mechanisms of cognitive evolution, not limited to working memory, “can only be a good thing” (p. XXX)

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