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News and Views

Modern cognition in the absence of working memory: Does the working memory account of Neandertal cognition work?

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There are difficulties in attempting to derive a picture of the mental life of early humans. These difficulties are particularly severe when the cognitive neuropsychology of modern adults is taken as the basis for such an attempt. Cognitive neuropsychologists assume that one can tell something about ‘‘normal’’ mental operation by examining what happens when certain cognitive components are absent (e.g., following brain damage). There are limitations to the inferences that can be safely made using this method, even when it is restricted to modern *Homo sapiens* (Shallice, 1998), but in a thought-provoking series of articles, Wynn and Coolidge (2003, 2004; Coolidge and Wynn, 2004, 2005) have used this approach to suggest that Neandertals differed from modern humans in having ‘‘restricted working memory capacities’’ (Coolidge and Wynn, 2004: 61), resulting in a mode of processing that relied exclusively upon ‘‘expert’’ crystallized processes (Wynn and Coolidge, 2004). They are not unique in making this claim (e.g., Russell, 1996), and the evidential basis of such arguments deserves careful consideration.

The main point is whether the enhanced working memory (EWM), and in particular, enhanced phonological storage capability, claimed for modern humans relative to Neandertals is either necessary or sufficient to account for the apparent differences in symbolic thought between archaic (including Neandertal) and modern humans suggested by the archaeological record (e.g., d'Errico et al., 1998). Briefly, Neandertal populations are documented as demonstrating similar technology and foraging techniques to those of early modern humans and yet, over a period of approximately 150,000 years, this culture did not noticeably develop. The exceptions to this rule are the Châtelperronian assemblages found in southwestern France and northern Spain dating from between 42,000 to 32,000 years ago. These assemblages have no clear antecedent in previous Neandertal technology, and it is argued that they reflect the Neandertal reaction to the arrival of modern humans equipped with Aurignacian technology (Coolidge and Wynn, 2004). The question that remains unanswered is why the Neandertals experienced this ‘‘cultural stasis.’’ *Homo sapiens*, starting from approximately the same baseline as *Homo neanderthalensis*, developed Aurignacian and subsequent technologies whereas Neandertals seemingly remained fixated on the older Levallois techniques at which they were, as a group, already expert. Did they require the example of Aurignacian technology to make even the relatively small advances that resulted in the Châtelperronian assemblages? A related issue is why modern human sites from around 30 ka show evidence of cave-paintings and other representational art but similar symbolic behavior is absent from Neandertal sites (Mithen, 2005).

In arguing for working memory as the essential cognitive difference between modern humans and Neandertals, Wynn and Coolidge are following a well-trodden path in cognitive science by observing that the operations that, in principle, are possible for any given information-processing device (including the mind/brain) are dependent upon memory capacity (e.g., Chomsky, 1959; Johnson-Laird, 1983). Additionally, they provide an account based upon an ability that is known to be heritable, and hence biologically plausible. The term ‘‘working memory,’’ however, requires placement within a specific context. Baddeley (1996), for example, reviews at least

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three distinctly different uses of the term (cf. Neath, 2000). Progress can be made by restricting discussion to particular theories of human memory. There are numerous models of this form of working memory (e.g., Gathercole, 1996; Miyake and Shah, 1999), but the most influential of these is that of Baddeley (2003). To simplify matters, Baddeley's model will be referred to uncritically in what follows, as in the papers by Wynn and Coolidge.

The working memory model currently consists of four components (Baddeley, 2000, 2003), of which the phonological loop, which holds verbal material, is most important for current purposes. Among other possibilities, Coolidge and Wynn (2004, 2005) argued that a relatively simple mutation specific to phonological storage may have produced fully modern thinking (Wynn and Coolidge, 2004), and this possibility is the one specifically addressed here. Enhancement to the phonological storage component is linked, within the EWM hypothesis, to the evolution of speech and language, the argument being that enhanced phonological storage makes modern linguistic competence possible. Prior to this, the lack of such enhanced memory capacity restricted the creative and cultural capabilities of Neandertal cognition. A further possibility, that executive control elements associated with frontal lobe functioning are also enhanced in modern relative to archaic cognition (Coolidge and Wynn, 2001, 2005), will not be addressed, as this issue is less original (Russell, 1996; Goldberg, 2001) and, because of a lack of theoretical specificity, less susceptible to direct test.

The phonological loop in modern and archaic cognition

The phonological loop, the most detailed and well-researched component of Baddeley's working memory model, comprises a phonological store, which holds speech sounds for around 1.5 to 2.0 seconds, and an articulatory rehearsal system or "loop" that refreshes the decaying memory traces. A major point in the argument for phonological storage as a key construct in the evolution of modern cognition is the idea that phonological storage is a bottleneck in language comprehension. Hence, the EWM hypothesis would suggest that a lack of phonological storage capacity prevents full and effective use of language. Coolidge and Wynn (2005: 13–14) repeatedly cited Baddeley and Logie (1999) as contending that "the phonological loop might be considered a major bottleneck in the process of language comprehension, and it would certainly be a bottleneck in language production" (see also Wynn and Coolidge, 2004: 481).

However, this attribution is inaccurate. Firstly, as noted elsewhere (Coolidge and Wynn 2004: 60–61), the view that phonological storage is a bottleneck for speech production is a new hypothesis and is not ascribable to Baddeley and Logie (1999). Secondly, Baddeley and Logie's view on phonological storage as a bottleneck for language comprehension is a misrepresentation. Baddeley and Logie (1999: 41) stated that the phonological loop "might reasonably be considered to form a major bottleneck in the process of spoken language comprehension," but they also noted that:

> This view would predict that the comprehension limits of a patient with an STM [short-term memory] deficit would be set by the length of sentence that could be held in memory. In general this is not the case, however. *STM patients typically show only minor comprehension problems* (Baddeley and Logie, 1999: 41, emphasis added).

This fuller account of Baddeley and Logie's position regarding the minor role played by phonological storage in language comprehension is in line with their earlier statement:

> Patients with impaired verbal short-term memory (STM) appear to be able to encode material quite normally, in the sense of perceiving words and sentences… [and] *often have a normal capacity for speech production* (Baddeley and Logie, 1999: 33, emphasis added).

Thus, far from claiming phonological storage as a bottleneck in language use, Baddeley and Logie are at pains to deny any such role either for language comprehension or production, contrary to the claims made in the case for EWM as the key to modern cognition.

Baddeley and Logie's (1999) opinion carries great weight but, given the emphasis placed by the EWM hypothesis on the cognitive benefits of phonological storage, it is unwise to rely on authority. Wynn and Coolidge (2004: 482) suggested that an abbreviated phonological store might result in "dramatic language differences between humans and Neandertals," with Neandertals limited to declarative, imperative, and exclamatory modes of speech. The literature on the capabilities of patients with impaired phonological storage as a consequence of head injury does, however, confirm Baddeley and Logie's conclusion rather than Wynn and Coolidge's. Severe brain damage resulting in much-restricted verbal short-term memory need not compromise language capability in any significant way. Contrary to popular mythology, patients with impaired verbal short-term memory often show a remarkably preserved everyday function (e.g., Butterworth et al., 1986, 1990; McCarthy and Warrington, 1990). Such patients can only reliably repeat back a string of one or two letters, digits, or words (Shallice and Vallar, 1990) compared to an adult average of seven plus or minus two completely correct strings (Miller, 1956), so their working memory deficits are severe, but higher-level cognitive and linguistic capabilities are frequently unimpaired. Thus, Coolidge and Wynn's argument that expanded phonological storage capacity has "provocative implications for language" is based upon a misinterpretation and is contrary to neuropsychological evidence explicitly ruling out the possibility that either spoken-language comprehension or speech production are critically dependent upon phonological working memory.

This analysis can be taken further. Within Baddeley's phonological loop model, short-term working memory problems can be attributed either to deficient phonological storage or rehearsal difficulties. Wynn and Coolidge (2004) speculatively suggested that greater phonological storage would be associated with increases in syntactical complexity, morphemelogical richness, and an enhancement of the pragmatics and modes of speech, including the subjunctive mode of speech and consequent use of hypothetical modes of thought. They also suggested that increased phonological storage may allow modern humans greater articulatory rehearsal, allowing for better long-term storage, greater self-reflection and the beginnings of introspection (Wynn and Coolidge, 2004: 481; Coolidge and Wynn, 2005: 13–14), and even the beginnings of language-based humor (Wynn and Coolidge, 2004: 482–483). It would be strong evidence for their claims if neuropsychological patients suffering from short-term-memory problems associated with either the phonological store or the articulatory loop routinely also showed difficulties in producing or understanding complex syntax, subjunctives, and hypotheticals, or alternatively, could be shown to suffer from relatively poor long-term storage, or the impaired powers of self-reflection or introspection predicted by the EWM hypothesis. Of these possibilities, there are no reports in the literature of impairments to self-reflection, introspection, or long-term storage reliably occurring among short-term-memory patients. Additionally, the original finding of impaired short-term with preserved long-term memory (patient KF; Warrington and Shallice, 1969) is one reason why Baddeley's working memory theory, in which long-term encoding is not dependent upon short-term storage (see Fig. 1), replaced earlier models of memory structure. Thus, there is no empirical evidence that articulatory rehearsal promotes the cognitive advantages considered within the EWM hypothesis. It is not associated within the literature with self-reflection or introspection, and case studies of preserved long-term-memory storage in the absence of short-term retention are plentiful (Vallar and Shallice, 1990; Vallar, 2006).

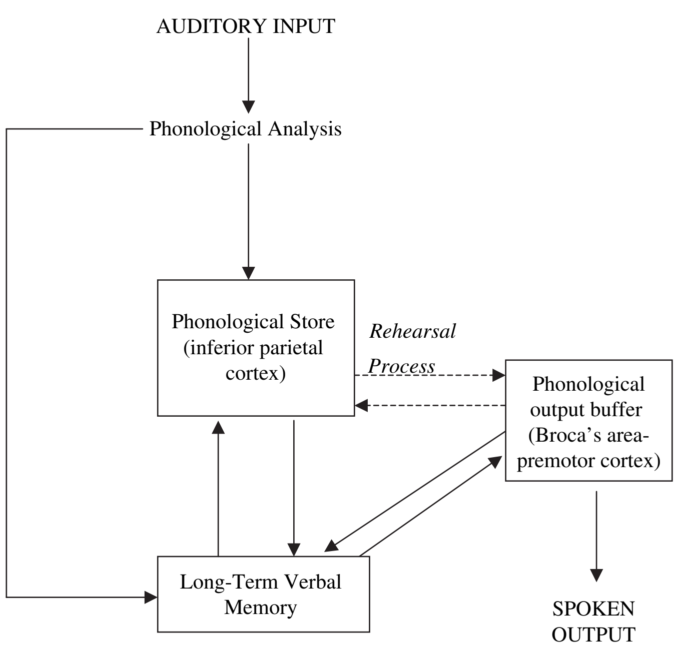

Fig. 1. A diagrammatic representation of the verbal working memory system, adapted from Vallar (2006). Boxes represent functionally distinct hypothetical memory stores and arrows represent hypothetical memory encoding, recoding, and consolidation processes. Where available, suggested neural bases of the hypothetical memory stores are marked in parentheses.

There is evidence that impaired phonological storage may be accompanied by problems with complex syntax, although these occur only when comprehension requires verbatim, rather than gist, memory for information and across several intervening words (Vallar and Baddeley, 1984, 1987). This is consistent with Baddeley and Logie (1999) and with Shallice's (1988) contention that phonological storage may act only as a "back-up" system for linguistic analysis. No reports have yet been published documenting difficulties in dealing with hypotheticals among short-term-memory patients. Figure 1 provides a diagrammatic representation of the phonological storage system based upon recent neuropsychological evidence. The relationship between phonological storage and other cognitive processes is clearly laid out, and it is obvious that phonological storage per se is not a unique access route for subsequent language processing or cognition and therefore is unlikely to constitute the "bottleneck" claimed within the EWM hypothesis. Language is supported by multiple cognitive processors, the increasing coordination of which might prove a more fruitful basis for the evolution of the spoken word than enhancement of a single component (cf. Aboitiz et al., 2006; Martín-Loeches, 2006).

Wynn and Coolidge (2004) rightly pointed to the dangers of assuming that the behavioral sequelae of brain damage are the same as the sequelae of restricted phonological storage, although if brain damage has the functional effect of restricting phonological memory, then it is difficult to see how the preserved behavioral capabilities of brain-damaged patients can fail to tell against the idea that phonological working memory is the necessary cognitive antecedent to behavioral flexibility. Nevertheless, an alternative to the cognitive neuropsychological approach adopted by Wynn and Coolidge is the application of developmental cognitive genetics, which focuses on inherited and developmental brain anomalies rather than acquired brain disorders, and where there has been some suggestion that specific language impairment (SLI)—including problems with syntax—is caused by poor phonological storage (Tallal, 2000). Further research, however, discounted this possibility and indicates that syntax develops normally in such children unless they have hearing impairments in addition to poor phonological memory (Bishop, 2006). Thus, in the developmental case as in the acquired case, there is no evidence that the absence of enhanced phonological memory precludes the effective use of language.

In sum, the case that an EWM specific to the phonological loop is responsible for the emergence of modern thought seems to be evidentially rather weak. Modern humans with damage to their verbal short-term-memory systems show no sign of the difficulties one might expect if they were reliant only on archaic cognitive mechanisms, as suggested by Wynn and Coolidge (2004). There is one possible exception to this rule, and it is that phonological storage appears to be necessary for learning new vocabulary (Baddeley et al., 1998), although its role may be restricted to learning new speech sounds (phonology), not new meanings (Freeman and Martin, 2001). Even in this regard, however, there is at least one report of a case with impaired short-term memory but preserved first (but not second) language acquisition, suggesting that other cognitive capabilities can, under certain circumstances, take the role of phonological storage in vocabulary learning (Baddeley, 1993).

Results of studies attempting to model the relationship between short- and long-term memory also indicate that the phonological storage system need not be particularly large or "enhanced" to allow vocabulary learning to develop and that capacity differences are not necessary to drive developmental change (Jones et al., 2005, personal communication). It is clear that, with an assumed trace duration of only 1.5 to 2.0 seconds, if phonological storage in modern humans is considered "enhanced," then it is still, by most standards, remarkably small [too small to "create and store more elaborate stories" (Wynn and Coolidge, 2004: 482), which in any case would be episodic rather than phonological in format] and, as Donald (1993) argued, is too transient and too vulnerable to distraction to manage any major cognitive project [e.g., background noise causes an average 30–50% increase in errors in recalling from short-term working memory (Beaman, 2004)]. Arguments of the same kind were made by Ericsson and Kintsch (1995: 212–213). This runs contrary to the central claim of EWM that working memory is of "appropriate magnitude" to grant it priority over other proposed keys to modernity (Coolidge and Wynn, 2004: 60). The subsequent claim that contingency planning, innovative plans of action, temporally remote action (organizing actions to be performed at a remote time or space), and the use of cultural algorithms to streamline problem-solving all require the phonological store to encode, hold in attention, and relay the complex relationships (Coolidge and Wynn, 2005: 16) also lacks conviction. There is no evidence from the population of patients suffering from impaired phonological storage that they reliably show difficulties on these types of task (Vallar and Shallice, 1990). Neandertals may well have made use of expert memory, as postulated by Wynn and Coolidge (2004), but this hardly makes them unique among humans or nonhuman primates. However, Wynn and Coolidge's account is thought-provoking, and even if phonological loop functioning is dismissed, a "general" working memory limitation among Neandertals cannot currently be ruled out, if only because the concept is broad enough to take multiple alternative interpretations (Miyake and Shah, 1999; Neath, 2000). Regardless of the usefulness of a more general working memory account, Coolidge and Wynn appear to have anticipated, or precipitated, an increase in cross-disciplinary theorizing regarding mechanisms of cognitive evolution not limited to working memory (Amati and Shallice, in press; Barnard et al., in press; Coolidge and Wynn, 2004, 2005; Marcus and Rabagliati, 2006; Aboitiz et al., 2006), and this can only be a good thing.

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