



News and Views

## On the uniqueness of humankind: is language working memory the final piece that made us human?

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### The enhanced working memory (EWM) hypothesis

Recently, Frederick Coolidge and Thomas Wynn have developed an appealing hypothesis according to which a single additive genetic mutation might have increased working memory capacity in our species. As a consequence of this enhanced working memory (EWM), modern mind would emerge (Coolidge and Wynn, 2001, 2005; Wynn and Coolidge, 2004). This change would have been modest and added to the abilities already possessed by pre-modern populations, who would nevertheless have achieved a high degree of cognitive capabilities but just needed this EWM to become plainly modern humans (Wynn and Coolidge, 2004). There would be at least two possible scenarios for EWM to occur. In one, the mutation causing EWM accompanied the evolution of anatomically modern humans prior to 150 ka in Africa, where it then enabled the gradual development of modern behavior. In the other, the mutation occurred after 100 ka and produced behavioral modernity in groups that were already anatomically modern (Wynn and Coolidge, 2004; Coolidge and Wynn, 2005).

According to the model on which Coolidge and Wynn are basing their hypothesis, working memory is a tripartite cognitive system consisting of a central executive, primarily involved in maintaining attention and decision-making, and two slave systems (see Baddeley, 2001 for a review). One of these slave systems is the phonological loop, which consists

of a phonological short-term store and the articulatory rehearsal processes by virtue of which information within the phonological store is refreshed in order to avoid decay. A daily example of the use of the phonological loop is when a just-heard telephone number has to be remembered for a short time before dialing it. The other slave system is the so-called visuospatial sketchpad that, although less known and investigated than the other slave system, could be considered as similar to the phonological loop but devoted to transiently storing visual and spatial material.

Coolidge and Wynn propose two possible mechanisms for EWM. One is that the mutation causing EWM occurred in the non-domain specific capacity of working memory, the central executive. The second is that it was a domain-specific mutation in one of the slave subsystems of working memory, the phonological loop (Wynn and Coolidge, 2004; Coolidge and Wynn, 2005).

If the mutation were specific to the phonological loop, its impact on language would have been a direct one. Coolidge and Wynn cite in this regard a proposal by Baddeley and Logie (1999) that the phonological loop may be the bottleneck of language comprehension and production. Subsequently, Coolidge and Wynn suggest: “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” (Wynn and Coolidge, 2004, p. 482). These authors also postulate that greater phonological storage would allow greater morphemological richness as much as increases in syntactical complexity, so that sentences could be longer, contain more information, and imply more complex relationships by virtue of

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syntactical embedding. Hence, more information, including past and future events, could be manipulated by means of language, then facilitating inter-modular thinking as much as the “loading up” of a great amount of additional information in a single spoken or subvocalized thought. Last but not least, increased phonological storage would serve to create and store more elaborate stories, then permitting myth-making and storytelling abilities, presumably not present in pre-modern populations (Arsuaga, 2001).

On the other hand, Coolidge and Wynn (2005) alternatively propose that if the mutation were specific to the central executive, its impact on language would not be different than on other cognitive systems. The central executive in Baddeley’s model subsumes most of the traditionally defined aspects of executive functions (Baddeley, 2001): focusing attention (including the blockage of distractors), making decisions, planning, sequencing, temporal tagging, and being a liaison to long-term memory systems and to language comprehension and production. The central executive would also allow for ‘thought experiments,’ which are critical to the development of the advancement of knowledge or creativity. The central executive would also be related to general intelligence and fluid intelligence (that part of intelligence depending less on schooling and acculturation) (Kane and Engle, 2002). The central executive would also be responsible for the updating, maintenance, integration, and control of the two slave systems.

To conceive and support their model, Coolidge and Wynn provide a large amount of data and evidence from cognitive psychology and neuroscience, cognitive anthropology, archaeology (and its derivative, cognitive archaeology), and genetics. As the author of the present work is indeed convinced of the validity of, or at least has the highest interest in Coolidge and Wynn’s proposal, it is his purpose to lend a hand by raising several points on which the model might be obscure or perhaps be open to further discussion and revision. My expertise is in the disciplines of cognitive psychology and neuroscience. Accordingly, it will be these areas of knowledge to which the points raised here will mainly pertain.

### **The central executive: nothing new under the sun**

My comments about enhancement of the central executive capacity as the place where EWM could have occurred are in fact implicit in Coolidge and Wynn’s proposal. These authors have already noticed that considering this component as part of working “memory” is in fact incidental, and that its description is far from different than the one used for executive functions. This has the advantage of being in line with many classical proposals on what “made us human” (Eccles, 1989; Russell, 1996; Deacon, 1997; Goldberg, 2001). But this has in turn a disadvantage: proposing an enhancement of the capacity of the executive functions would not be a truly new idea.

### **The language processor**

In contrast, the alternative of EWM as specific to the phonological loop is the most appealing and original suggestion in

Coolidge and Wynn’s proposal. But it is here where additional problems may lie. These authors confer to this slave system a steep leading role in the appearance of the syntax processes that convert our language in an outstanding attribute.

Indeed, Baddeley and Logie (1999; see also Baddeley, 2003) suggested that the phonological loop may be the bottleneck of language comprehension and production. But being the bottleneck does not mean it is the crucial factor, as bottlenecks for language comprehension and production would also be our ears and our tongue. Rather, the role of the phonological loop in these processes would be that of permitting better phonological discrimination, necessary to achieve language comprehension and production in better conditions. In fact, the evidence provided by Baddeley and Logie (1999) mainly refers to the capacity to learn a new language.

But the relevance of the phonological loop for syntax acquisition is definitely weaker when considering the bulk of evidence from the psycholinguistic and neurolinguistic literature. As Wynn and Coolidge (2004) note, the typical measure of the phonological loop is the Digit Span Subtest of the Wechsler Adult Intelligence Scale (e.g., Lezak, 1995), which requires subjects to repeat increasingly long strings of numbers forwards and then backwards. However, from the psycholinguistics perspective it appears as a solid and established statement that digit span and working memory for language comprehension are far from the same.

Daneman and Carpenter (1980) already noticed this discrepancy, then proposing a test specifically designed to measure linguistic working memory, the Reading Span Test, in which subjects are required to recall sentence-final words in sets of sentences. At first glance, it may seem that the Reading Span Test is measuring something that is not far from what is measured by the Digit Span Test. However, the Digit Span Test and Reading Span Test actually correlate very poorly (King and Just, 1991), yielding correlation values of less than 0.20 (i.e., less than 4% of common variance), and it is far from rare to find subjects with both very good rates in one test and very poor ones in the other.

The work by Daneman and Carpenter (1980) gave credence to at least two diverging proposals for linguistic working memory. On the one hand, Just and Carpenter (1992) proposed that linguistic working memory would be unitary, a single resource used for language comprehension. On the other hand, Waters and Caplan (1996; see also Caplan and Waters, 1999) proposed the existence of at least two subdivisions within language working memory. One resource would be referred to as the “psycholinguistic resource pool” or “interpretive processing”, which is more automatic and highly demanded (among other processes) by syntactically complex sentences, whereas the other, called “post-interpretive processing”, is more controlled and is used for tasks such as verbal reasoning or the deliberate search of information in semantic memory. But, indeed, both models persist on the idea that a separate working memory system is devoted to language comprehension and includes, as a main specific (but not exclusive) function, syntax processes. This system is to a great extent independent and encapsulated relative to the phonological loop.

Many of the subsequent models in psycholinguistics and many authors in the neurocognitive approach take for granted that linguistic working memory is an independent system, one of whose main tasks is syntax operations. In this respect, some portions of Broca's area seem involved specifically in syntactic working memory (e.g., Fiebach et al., 2005). It is still a matter of debate, nevertheless, whether linguistic working memory is a unitary resource (as Just and Carpenter, 1992 maintain) or if it is composed of several modular linguistic resources, each with its own working memory capacity (as Waters and Caplan, 1996 maintain). Although the system as a whole could still be called linguistic working memory, perhaps it is more appropriate to call it the language processor or language processing capacity, consistent with more recent accounts (MacDonald and Christiansen, 2002).

Accordingly, many of the virtues proposed by Coolidge and Wynn for the phonological loop should be directed to the language processor. This would include not only morphemological richness and syntax or syntactic complexity, but also the ability to create and store more elaborate stories, and then to attain myth-making and story-telling abilities. The phonological loop, at least as understood in the proposal by Baddeley (2001, 2003), only concerns phonological information, but disregards and explicitly excludes many other features that characterize human language, including the highly relevant syntax processes.

In light of the EWM hypothesis, it could then be suggested that the modern mind could be a consequence of modern language, which in turn could be the consequence of an EWM affecting the language processor, a processor that comprises syntax as a main specific function. Furthermore, and still in the frame of Coolidge and Wynn's proposal, the question of interest could indeed be whether this language processor appeared as a whole in our species, then yielding our modern mind, or whether this end was achieved by enhancing the capacity of an already existing language processor. In my view, the second option remains possible (Jackendoff, 1999; Casado et al., 2005; but see Hauser et al., 2002 for an opposing view).

### **The limited resources of the language processor and the number of active neurons**

In several studies of event-related brain electrical potentials (ERP), it has been shown that good language comprehenders (either as measured by the Reading Span Test or by performance measures) display larger amplitudes of certain ERP components reflecting syntax processing than do bad comprehenders (e.g., King and Kutas, 1995; Vos et al., 2001). It has also been shown that these ERP components notably reduce in amplitude when parallel demands on certain linguistic working memory operations are being tapped (Vos et al., 2001; Martín-Loeches et al., 2005). These, as much as a large bulk of previous evidence, clearly indicate that the language processor is of limited capacity, and that its limited resources must be shared among qualitatively different subprocesses.

To the extent that the amplitude of an ERP component is a function of the number of neurons involved (Picton et al., 1995; Proverbio and Zani, 2003), it could be suggested that

a main difference between good and bad comprehenders may relate to the amount of neural tissue involved in language processing. Accordingly, differences in language processor capacity could be defined in terms of the number of neurons that can be activated simultaneously within certain brain regions.

Then, from a neurological perspective it can be suggested that EWM, by virtue of which modern mind emerged, could be defined as an increase in the number of neurons that can be activated in parallel (the number of "working neurons"). With this suggestion in mind, it might be suitable and probably even simpler to search for possible genetic loci responsible for this feature. Indeed, it appears plausible that the single additive genetic mutation yielding EWM, modern mind, simply increased the amount of neural tissue that can be activated simultaneously or in parallel. As a result, it would not be necessary to appeal to an absolute brain size increase or even to any type of brain reorganization (in the strict sense of modifying the shape of the neural circuits) in order to attain a modern mind. That is, to achieve an EWM, an anatomical shift would not be necessary: an already anatomically modern brain could become behaviorally (functionally) modern by simply increasing the number of neurons that can be activated in parallel. Hence, the second possible scenario for EWM proposed by Coolidge and Wynn (see above) would appear even more easily admissible.

This enhanced number of simultaneously active neurons could be achieved by at least two non-mutually excluding means. One, which nevertheless implies some degree of anatomical change and reorganization, is that the overall number of existing neurons for a given function is augmented. The other is that, keeping constant the number of neurons, some metabolic or other functional cell features permit more neurons to be activated simultaneously. It is this second mechanism that needs to be explored further.

Currently, several genetic loci appear as possible, non-mutually excluding candidates for these changes. Perhaps one of the best of these candidates, which is explicitly mentioned by Coolidge and Wynn, and suitably accounts for both mechanisms, is *FOXP2*. It has been shown that anomalies of this gene may cause both structural (number of existing neurons) and functional (number of activated neurons) abnormalities in certain brain regions related to language (Vargha-Khadem et al., 1998). But other candidates also exist. The recent work by Evans et al. (2005) and Mekel-Bobrov et al. (2005) indicates that two genes involved in neural cell proliferation (*ASPM* and *MCPHI*), then related to the number of existing neurons, have evolved recently and continue to evolve adaptively in humans. Alternatively, the study by Hayakawa et al. (2005) reveals that certain genes involved in glial expression (affecting neural metabolism) are human-specific (as *SIGLEC11*), although it has yet to be determined how these genes have evolved along the human lineage.

### **Final comment: EWM specific only to the language processor?**

If working memory were defined as the number of neurons that can be activated simultaneously, the dichotomy between

the phonological loop (or, rather, the language processor) and the central executive as the locus for EWM as proposed by Coolidge and Wynn could be academic. Instead, EWM could have occurred in overall terms; that is, it was the number of neurons that can be activated simultaneously which was enhanced, regardless of whether these neurons belong to one or another partition within the immense neural network constituting the human brain. This is something that must be explored. Regardless, the work by Coolidge and Wynn that presents evidence in favor of the two alternatives (linguistic processes and executive functions) is a clear indication that the EWM could have occurred in both components of the working memory system concurrently. Indeed, it remains possible that EWM also affected other possible domain-specific working memory systems, including the phonological loop and the visuospatial sketchpad.

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