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Low working memory capacity is only spuriously related to poor reading comprehension

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ABSTRACT

Accounts of comprehension failure, whether in the case of readers with poor skill or when syntactic complexity is high, have overwhelmingly implicated working memory capacity as the key causal factor. However, extant research suggests that this position is not well supported by evidence on the span of active memory during online sentence processing, nor is it well motivated by models that make explicit claims about the memory mechanisms that support language processing. The current study suggests that sensitivity to interference from similar items in memory may provide a better explanation of comprehension failure. Through administration of a comprehensive skill battery, we found that the previously observed association of working memory with comprehension is likely due to the collinearity of working memory with many other reading-related skills, especially IQ. In analyses which removed variance shared with IQ, we found that receptive vocabulary knowledge was the only significant predictor of comprehension performance in our task out of a battery of 24 skill measures. In addition, receptive vocabulary and non-verbal memory for serial order—but not simple verbal memory or working memory—were the only predictors of reading times in the region where interference had its primary affect. We interpret these results in light of a model that emphasizes retrieval interference and the quality of lexical representations as key determinants of successful comprehension.

1. Introduction

The centrality of memory operations to language comprehension has long been recognized: it was 50 years ago, for example, that Miller and Chomsky (1963, chap. 13) proposed that there is an endogenous upper bound on the number of noun phrases that can be manipulated in memory during sentence processing. This theoretical perspective – that capacity constrains language comprehension – was reinforced by the subsequent development of Alan Baddeley's model of working memory (e.g., Baddeley & Hitch, 1974; Baddeley (1986, 2000); Repovš & Baddeley, 2006), in which a single, finite pool of processing resources supports both storage and computation. Given the pervasive influence of Baddeley's model, it is unsurprising that most theories of comprehension skill incorporate working memory capacity, often in a central way (e.g., Engle, Cantor, & Carullo, 1992; Gibson, 1998; Just & Carpenter, 1992; see Long, Johns, & Morris, 2006, for a review). According to these accounts, humans possess a limited supply of neural "resources" with which to support cognitive operations during sentence processing. As the computational demands of ongoing comprehension increase, the resources available to keep items active in

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working memory decrease; conversely, as memory demands increase, there will be fewer resources available for comprehension processes. Exceeding available resources results in either loss of information from working memory, impaired processing (e.g., syntactic parsing, semantic integration, etc.), or both. The classic demonstration of this is the contrast between subject- and object-extracted relative clauses (RCs), in which the latter are more difficult to process than the former; the reason for this difficulty is thought to derive from the need to actively maintain the initial noun phrase (e.g., *The banker*) in object RCs while processing the embedded clause, after which it can be integrated with its verb phrase (e.g., *climbed*).

(1a) OBJECT RC: The banker that the barber praised climbed the mountain.
(1b) SUBJECT RC: The banker that praised the barber climbed the mountain.

On this account, individual differences in sentence comprehension arise because of intrinsic differences in the total capacity of the resource pool: individuals with smaller total capacity will show impaired comprehension relative to high capacity individuals, especially with complex sentences that require additional computations. Numerous studies have demonstrated the crucial interaction of memory capacity and sentence difficulty: when compared to their high capacity peers, low capacity participants appear to have greater difficulty not only with object RCs (compared to subject RCs), but also with a host of other complex constructions (e.g., Just & Carpenter, 1992; King & Just, 1991; Long & Prat, 2008; MacDonald, Just, & Carpenter, 1992; Nieuwland & Van Berkum, 2006; Traxler, Williams, Blozis, & Morris, 2005).

Despite the prevalence of the idea that a capacity-based memory architecture supports language processing, there is now a broad base of empirical evidence indicating that the amount of information that can be actively maintained in memory during sentence processing is very limited—even for skilled readers. Based on the premise that elements that are maintained in active memory should be accessed more quickly than those passively stored in LTM, a number of studies have utilized precise measures of retrieval speed to determine the size of available, active memory (see McElree, 2006, for a review). For example, in list-learning paradigms, the consistent result is that a speed advantage is only observed for the most recently studied item (McElree, 1996, 1998, 2001, 2006; McElree & Dosher, 1989, 1993; Wickelgren, Corbett, & Dosher, 1980; Öztekin & McElree, 2007). Similarly, in studies of sentence processing, the consistent result is that only the most recently processed linguistic constituent exhibits increased accessibility (McElree, 2000; McElree, Foraker, & Dyer, 2003; Wagers & McElree, 2009). This presents a strong challenge to the capacity view, in which multiple propositions, syntactic structures, or entire interpretations are thought to enjoy increased accessibility by virtue of being actively maintained in working memory.

In addition, there are important theoretical reasons for believing that an emphasis on capacity does not optimally characterize the constraints that the memory system places on language comprehension. Capacity is thought to matter because information that is not maintained is lost—pushed out of active memory by the demands of other processing, and lost because the consequent inattention results in decay (Gibson, 1998, 2000; Just & Carpenter, 1992). However, this approach is problematic in light of extensive research in the memory domain suggesting that interference, and not decay, is the primary source of forgetting (e.g., Underwood & Keppel, 1962; Waugh & Norman, 1965; see Berman, Jonides, & Lewis, 2009, for a more recent assessment). Interference arises when retrieval cues are insufficient to uniquely identify a target item; in such cases, cues are said to be "overloaded," and distracting items, which share some features with the intended target, are erroneously retrieved instead (e.g., Nairne, 2002; Watkins & Watkins, 1975; Öztekin & McElree, 2007). Although interference effects were originally investigated in the memory domain, there is now a substantial body of evidence demonstrating interference effects in language comprehension (see Van Dyke & Johns, 2012, for a review). For example, in sentence processing, Van Dyke (2007) observed interference effects from a semantically similar distractor (e.g., *neighbor*) when the animate NP (*resident*) must be retrieved as the VP *complained* is parsed (e.g., (2b), as compared with (2a), where the potential distractor *warehouse* is not animate). This occurs despite the presence of syntactic cues that could eliminate the distractor as a potential subject of *complained*.

(2a) The resident who was living near the dangerous warehouse complained about the noise.
(2b) The resident who was living near the dangerous neighbor complained about the noise.
(2c) The resident who declared that the warehouse was dangerous complained about the noise.
(2d) The resident complained about the noise.

Distractors based on the match of syntactic cues alone also produce interference (Van Dyke & Lewis, 2003); thus, (2c) is also more difficult than (2a), because the intervening subject NP *warehouse* matches the syntactic retrieval cues from *complained*, which requires a subject NP to complete the long distance dependency. This finding contrasts sharply with the capacity-based view that complex sentences of this sort are difficult because they consume WM resources. That is, contra the capacity-based account, sentence (2c) is more difficult than (2a) despite having the same amount of intervening material (i.e., identical memory demands) between the dependent subject and verb (*resident-complained*). Further, sentence (2a), which contains neither a syntactic nor a semantic distractor for the subject of *complained*, was found to be no more difficult than sentence (2d), which contains no intervening material at all (Van Dyke & Lewis, 2003).

In addition to interference from semantic and syntactic cue overload, interference as a result of referential cues has also been observed. Gordon and colleagues (Gordon, Hendrick, & Johnson, 2001, 2004; Gordon, Hendrick, Johnson, & Lee, 2006) found that sentences whose nouns were of the same referential type (e.g., both descriptive nouns, as in (3a), underlined) were more difficult than