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Individual differences in semantic short-term memory capacity and reading comprehension

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Abstract

We report three correlation studies, which investigate the hypothesis that individual differences in the capacity of a semantic short-term memory (STM) component in working memory (WM) predict performance on complex language tasks. To measure the capacity of semantic STM, we devised a storage-only measure, the conceptual span, which makes use of a category-cued recall procedure. In the first two studies, where the conceptual span was administered with randomized words (not blocked by categories), we found that conceptual span predicted single-sentence and text comprehension, semantic anomaly detection and verbal problem solving, explaining unique variance beyond non-word and word span. In some cases, the conceptual span explained unique variance beyond the reading span. Conceptual span correlated better with verbal problem solving than reading span, suggesting that a storage-only measure can outperform a storage-plus-processing measure. In Study 3, the conceptual span was administered with semantically clustered lists. The clustered span correlated with the comprehension measures as well as the non-clustered span, indicating that the critical process is memory maintenance and not semantic clustering. Moreover, we found an interaction between subjects' performance on the conceptual span and the effect of the distance between critical words in anomaly detection, supporting the proposal that semantic STM maintains unintegrated word meanings.

Keywords: Short term memory; Working memory; Reading comprehension; Individual differences; Conceptual span; Reading span

It is widely recognized that a limited-capacity working memory (WM) system plays an important role in complex cognition, supporting both the temporary storage and processing of information (for a review see Kintsch, Healy, Hegarty, Pennington, & Salthouse, 1999). A seminal study by Daneman and Carpenter (1980) demonstrated the importance of WM in the domain of language processing. Its major finding was that a storage-plus-processing measure of WM, *the reading span*, predicted accuracy of text comprehension (see also Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Budd, Whitney, & Turley, 1995; Daneman & Carpenter, 1983; Dixon, Le Fevre, & Twilley, 1989; Engle, Cantor, & Carullo, 1992; LaPointe & Engle, 1990; Masson & Miller, 1983), while a storage-only measure, *the word span*, did not (see also Turner & Engle, 1989). Moreover, when a statistically significant correlation between word span and comprehension is obtained, it tends to be smaller than the correlation between reading span and comprehension (LaPointe & Engle, 1990). The reading span test determines the number of sentence-final words a person can recall immediately after reading aloud a set of sentences and thus emphasizes both storage and processing of words. By contrast, the word span is a storage-only measure, which determines the number of

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words a person can recall in exact serial order immediately after their presentation. Consistent with the WM interpretation of the reading span test, Daneman and Carpenter (1980) found that the ability of low span readers to answer a question about the referent of a pronoun showed a marked deterioration when the number of sentences intervening between the referent and the pronoun was increased, while no such effect was present for high span readers. Furthermore, reading span is a good predictor of word reading times in sentence comprehension (for a review see Just & Carpenter, 1992; Miyake, Just, & Carpenter, 1994b).

While the correlation between comprehension and reading span is well established, its WM interpretation has been subject to debate (Baddeley et al., 1985; Daneman & Merikle, 1996). Jackson and McClelland (1979) found that listening comprehension is one of the most important predictors of reading comprehension. Together with a measure of letter matching it predicted 77% of the variance. Citing this result, Baddeley et al. (1985) asked "How should the correlation between comprehension and working memory span be interpreted?" and suggested that

> The original Daneman and Carpenter result was open to a range of interpretations, from the strong suggestion that their task was a measure of the capacity of a general working memory system, to the relatively weak interpretation that since working memory span itself depended on comprehension, that they were basically replicating the observation of Jackson and McClelland that listening comprehension was the best predictor of reading comprehension (Baddeley et al., 1985, pp. 129–130).

Thus, it seemed possible that the correlation between comprehension and reading span was somewhat trivial, that is, due to a great deal of overlap between the two tasks, in particular, their common sentence processing component. This interpretation was further discussed by Daneman and Merikle (1996) who rephrased it as: "*sentence comprehension (reading span ...) correlates with paragraph comprehension (the criterion comprehension tests)*" (p. 424). Indeed, Daneman and Carpenter (1980) suggested that the inclusion of a sentence processing task in both reading span and comprehension may be crucial to the ability of the reading span to predict comprehension. In particular, they suggested that in both tasks the temporary storage of verbal information could have been worse for poor readers who had to devote some of their limited WM resources to compensate for inefficient reading processes.

Subsequent research has ruled out this weak interpretation of the correlation between comprehension and reading span and has provided support for the stronger WM interpretation (Conway & Engle, 1996; Daneman & Merikle, 1996; Engle et al., 1992; Turner & Engle, 1989). Turner and Engle (1989) found that the background task of the complex span measure does not have to involve sentence processing in order to predict reading comprehension. They found that operation span predicts comprehension as well as reading span. Operation span measures the number of words or digits a person can retain while verifying a sequence of arithmetic problems presented in alternation with the to-be-retained words or digits. More generally, Daneman and Merikle (1996) concluded from a meta-analysis of data from 77 studies that complex span measures, which include a storage and processing component (e.g., reading span, operation span), predict comprehension better than storage-only measures (e.g., word span, digit span), even if the processing component of the complex span task does not involve manipulation of words and sentences. Furthermore, both reading span and operation span still predict comprehension, but to a lesser extent, when individual differences in processing efficiency are statistically controlled (Conway & Engle, 1996; Engle et al., 1992). This finding makes it unlikely that individual differences in complex span are solely due to inter-subject variation in the degree to which a constant capacity is allocated to compensate for differences in processing efficiency. Instead, such differences appear to reflect differences in the capacity of a WM system that supports both storage and processing (Just & Carpenter, 1992).

A shared assumption of all current models of WM is that it is a multi-component system (for a review see Kintsch et al., 1999). However, it is currently not well understood in what component of the WM system individual capacity differences predicting comprehension reside. One possibility is that there are individual differences in the capacity of a WM component that is crucial for dual tasking, that is, the ability to coordinate the performance of two tasks. For example, it has been suggested that individual differences in complex span performance could reflect differences in capacity to alternate attention between different tasks (Kane & Engle, 2000). This view correctly predicts that complex span measures (reading span, operation span) are better predictors of comprehension than simple span measures (word span, digit span), because the former but not the latter type of task involves a dual-task component.

It is nevertheless possible that a storage component plays also a role in predicting comprehension and that the impact of this factor has been underestimated, because most of the studies relied on a phonological measures of span (digit/word span using serial order recall). Recently a number of authors have suggested that the storage of verbal information is supported not only by a phonological short-term memory (STM) (Baddeley, 1986) but also by a semantic STM (Haarmann, Cameron, & Ruchkin, in press; Haarmann & Usher, 2001; Hanten & Martin, 2000; Martin & Freedman, 2001; Martin & Romani, 1994; Martin, Saffran, & Dell, 1996; Martin, Shelton, & Yaffee, 1994; Potter, 1993; Romani & Martin, 1999). In particular, a series of