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On the association between memory capacity and sentence comprehension: Insights from a systematic review and meta-analysis of the aphasia literature

Maria Varkanitsa[a,b,*], David Caplan[a]

[a] Neuropsychology Laboratory, Department of Neurology, Massachusetts General Hospital – Harvard Medical School, Boston, MA, USA
[b] Department of Linguistics, University College London, UK

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ABSTRACT

The role of short-term memory (STM) and working memory (WM) in sentence comprehension has been controversial; many neuropsychological studies and studies with neurologically intact individuals have revealed co-occurrence of STM/WM and sentence comprehension while other studies have found no relation between the two. The aim of this article is to revisit the association between memory capacity and sentence comprehension by systematically reviewing all relevant studies in the aphasia literature published between 1980 and June 2017. Emphasis was placed on the methods used in the eligible studies. The studies that reported data from correlation analyses exploring the relationship between sentence comprehension performance and performance on memory tasks were pooled in a group-level meta-analysis. The meta-analysis showed a correlation between the magnitude of performances on STM/WM tasks and performances on sentence comprehension tasks. Possible interpretations of this correlation are discussed.

1. Introduction

Linguistic stimuli arrive at sensory receptors over time and successful sentence comprehension depends upon the ability of the listener to maintain previous words and structures for sufficient time to allow for their combination into meaningful sentences. Sentence comprehension deficits in aphasia and other neurological conditions often co-occur with memory decline. Thus, on the intuitive level, the idea that some form of memory disturbance is responsible for sentence comprehension deficits in people with aphasia (PWA) is appealing. However, the nature of the relation between memory capacity and sentence comprehension abilities has not been fully specified; there is no consensus among researchers as to the memory system that supports sentence comprehension. In addition, neuropsychological data that are relevant to the association between memory and sentence comprehension are often insufficient to clarify whether any association of deficits is due to causal mechanisms.

Because the time over which sentence comprehension operates is short, many researchers have looked to models of short-term memory (STM) for mechanisms that support sentence comprehension. One of the most broadly applied models is Baddeley and Hitch's (1974) "working memory" (WM) model. This model included three primary components: the central executive, the phonological loop and the visuo-spatial sketchpad. The central executive was considered a supervisory system that contains a storage mechanism and a mechanism to allocate attention. In some versions of this model, the central executive includes a storage

* Corresponding author. Neuropsychology Laboratory Massachusetts General Hospital - Harvard Medical School, 100 Cambridge Street #2000, Boston, MA, 02114, USA.
E-mail addresses: mvarkanitsa@mgh.harvard.edu, maria.varkanitsa.09@ucl.ac.uk (M. Varkanitsa).

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mechanism and computational capacity (Just & Carpenter, 1992). The phonological loop and the visuo-spatial sketchpad were conceptualized as limited-capacity systems responsible for the short-term retention of phonological and visual or spatial information, respectively. Of particular interest for the purposes of this study is the distinction that can be drawn under this model between STM, which refers to the temporary maintenance of information, and WM, which refers to the maintenance and manipulation of information. In many studies, sentence comprehension deficits were thought to reflect a failure to maintain and rehearse phonological representations (Papagno, Cecchetto, Reati, & Bello, 2007; Vallar & Baddeley, 1984) or lexical-semantic information (Martin & He, 2004; Martin & Romani, 1994). There are also studies suggesting that the type of memory that is used for sentence comprehension is not the same as the one tapped by simple digit or other list span tasks. These studies emphasize the role of WM as a more dynamic memory system that supports sentence processing, by using complex span tasks, such as the Daneman and Carpenter Task (1980) and Kirchner's (1958) *n*-back task, that require information to be held while some process is performed (Caspari, Parkinson, LaPointe, & Katz, 1998; Wright, Downey, Gravier, Love, & Shapiro, 2007) – functions of the central executive. Just and Carpenter (1992) specifically endorse the central executive as the memory system that supports sentence and discourse comprehension.

A number of empirical data create problems for both these views. With regards to neuropsychological data, patients with Alzheimer's disease and severely impaired STM/WM have been shown to have intact comprehension of syntactically complex sentences (Caplan & Waters, 1995; Rochon, Waters, & Caplan, 1994; Waters, Caplan, & Hildebrandt, 1991; Waters, Caplan, & Rochon, 1995), and normal online syntactic processing, as shown by increased self-paced listening times associated with points of increased syntactic complexity (Almor, Kempler, MacDonald, Andersen, & Tyler, 1999). In addition, several studies report good sentence comprehension abilities in PWA despite their impaired STM/WM (Gvion & Friedmann, 2012; Martin & Romani, 1994; McCarthy & Warrington, 1987a,b). Finally, considering studies of neurologically intact individuals, individual differences in measures of WM have not been associated with individual differences in measures of real-time syntactic processing (Caplan, Dede, Waters, Michaud, & Tripodis, 2011; DeDe, Caplan, Kemtes, & Waters, 2004; Traxler, Morris, & Seely, 2002).

With regards to the role of memory systems in comprehension, we make a distinction between their role in the assignment of linguistic structure and the use of that structure to determine meaning (parsing and interpretation), and their role in using the products of those processes to perform a task. Parsing and interpretation is of special interest in studies of the role of STM/WM in comprehension because the units that constitute the input into the parser/interpreter (i.e.,words) are the most common stimuli in laboratory tasks that assess STM/WM, and the time scale over which memory operates in parsing and interpretation overlaps considerably with that of STM/WM. Testing the role of STM/WM in parsing and interpretation requires two methodological factors.

First, the sentences used in such studies be ones that cannot be understood without the operation of the parser/interpreter. This is achieved by presenting semantically reversible sentences (i.e., those in which semantic values such as thematic roles could plausibly be associated with several entities mentioned in the sentence) and using sentences in which the values that the sentence expresses cannot be assigned through non-syntactic heuristics. In practice, this requirement has been met by presenting semantically reversible sentences with complex syntactic structures. Second, it must be established that poor comprehension does not reflect difficulties at the lexical level. This requirement has been met by presenting "baseline" semantically reversible sentences that have simple syntactic structure (and that can be understood by heuristics) that have the same lexical items as the experimental, syntactically complex sentences. Finally, to study the question of whether STM/WM supports the memory requirements of particular syntactic operations, not simply the retention of words in a sentence, the baseline and experimental sentences must be matched for length.

Second, a great deal of parsing and interpretation occurs incrementally, as each word in a sentence and discourse is recognized, and the accepted behavioral measures of the activity of the parser/interpreter are ones that occur at those points, such as eye fixations in reading, eye fixations on pictures that correspond to entities named or thematic roles expressed in auditorily presented sentences, and, somewhat less directly, self-paced reading and listening times for words and phrases. Neurophysiological measures such as ERPs and MEG also fall in this category. With few exceptions, neuropsychological studies of STM and WM and comprehension do not use these on-line measures, and instead provide information about accuracy and reaction time in end-of-sentence tasks, such as answering questions about sentences and passages, making judgments about their plausibility, etc. A relation between STM/WM and the effects of sentence- and discourse-level variables (such as syntactic structure) in these measures would provide evidence for a role of these memory systems in encoding, maintaining and retrieving the products of parsing and interpretation processes in performing tasks, but not necessarily for a role for these memory systems in parsing and interpretation themselves.

Overall, although the type of the memory system that supports sentence comprehension – both narrowly conceived as parsing and interpretation *per* se and more broadly conceived as the use of the products of parsing and interpretation to perform a task – is still under debate, the notion that declines in STM/WM may hinder sentence comprehension remains possible. The aim of this article is to revisit the association between memory capacity and sentence comprehension by systematically reviewing the neuropsychological evidence from PWA. To the best of our knowledge, the last systematic review of all published literature on the topic of the relation of STM/WM and sentence comprehension was carried out by Caplan and Waters (1990). In that review, the authors focused on parsing and interpretation and presented findings from, and critically discussed, every paper that reported STM, WM and language comprehension that was published at the time. Since that review, many studies have presented data relevant to this topic, and therefore the approach in this review differs. Instead of presenting data from each paper individually, we review the methods employed in these studies and present the results of these studies by performing a meta-analysis that looks at the overall pattern of the relationship between STM/WM and sentence comprehension. That is, we analyzed studies that reported correlations between the magnitude of STM/WM performances and comprehension. Although correlation does not necessarily imply functional causation (in the case of

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