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Brain responses to syntax constrained by time-driven implicit prosodic phrases

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ABSTRACT

Previous research suggests that time-based working memory limits of 2–3 s constrain the integration of verbal information, and that speakers tend to parse sentences into prosodic phrases that do not extend beyond this time window. The present study used Event-Related Potentials (ERPs) to investigate how time-driven implicit prosodic phrasing influences the syntactic processing of embedded clauses. Participants read Swedish sentences in which the first embedded clause had a subordinate, main or neutral clause structure cued by the position of the sentence adverb. The presentation rate was manipulated so that either one or two clauses were read within 2.7 s. When the 2.7 s time limit was reached before the onset of the embedded clause, the sentence adverb indicating subordinate clause structure elicited a posterior negativity and a late positivity. These effects were interpreted to reflect the detection of unexpected word order, followed by the revision of the anticipated main clause structure. A positive shift that correlated with individual working memory span was also seen at the clause-final word after 2.7 s, possibly indicating closure of an implicit prosodic phrase. These results suggest that prosodic phrasing was influenced by time-based working memory limits, which in turn affected syntactic analysis: readers were more likely to interpret an embedded clause as a main clause if it could be associated with the beginning of a new prosodic phrase.

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1. Introduction

Baddeley (1997) proposed a 2–3 s long time limit constraining the duration of information that can be held in verbal working memory. This temporal limitation might derive from a more general neurocognitive principle that underlies the processing of sensory information. Based on the observation of a wide range of perceptual and production patterns such as movement sequencing and the segmentation of speech, Pöppel (1997) suggested that a temporal sequence within an interval of 3 s can be integrated and preserved as a unit. A specific implication for language processing is that there is a temporal constraint on the length of processing frames within which linguistic forms are sequenced and processed. According to Sachs (1974), formal aspects of discourse need to be recoded into longer-lasting (propositional) semantic representations while rapidly decaying formal (e.g. phonological, morphological and syntactic information) traces are still active in working memory. Prosodic phrasing seems to be adapted to these time-based working memory limits: Vollrath, Kazenwadel, and Krüger (1992) reported a median length of 2.6 s for intonation phrases in German conversations and Roll, Lindgren, Alter, and Horne (2012) showed that readers parsed utterances into 2.7 s long implicit prosodic phrases. Prosodic phrasing in turn has been observed to influence syntactic processing: embedded clauses following explicit prosodic phrase boundaries increased listeners' expectation of main clause structure (Roll, Horne, & Lindgren, 2009, 2011). The present study aims to extend these findings and investigate how implicit prosodic phrasing affects the parsing of embedded clauses as a result of time constraints on working memory. We manipulated the rate with which sentences were presented in order to vary the number of clauses that were read within the 2–3 s limit assumed to correspond to the duration of a prosodic phrase. Using event-related brain potentials (ERP), we tested whether readers have a tendency to analyze embedded clauses whose onset is beyond the assumed time window of about 3 s, i.e. at the beginning of a new prosodic phrase, as main clauses if no other cues are given indicating either subordinate or main clause interpretation.

1.1. Time-based constraints on working memory

In short-term recall of word sequences, performance has been found to decline as the temporal duration of words increases, indicating a time limit on the activation of verbal material (Baddeley, Thomson, & Buchanan, 1975). Based on the observed relationship between participants' reading rate and the amount of material they could recall, Baddeley et al. (1975) suggested that memory traces encoded in a temporary verbal memory store decay within 2 s unless maintained through rehearsal. A similar average interval of 2–3 s has been proposed to delimit the 'subjective present', during which successive events may be perceived as taking place at the same moment in time (Fraisse, 1984; Pöppel, 1997).

Alternative approaches to working memory that do not postulate distinct storage systems emphasize that both long-term and short-term memory processes rely on the same set of representations and retrieval mechanisms (e.g. Anderson et al., 2004; Cowan, 2000; Jonides et al., 2008; McElree, 2001). These accounts generally distinguish between a highly restricted focal state of memory defined by the number of chunks it can hold and a practically unlimited non-focal state. Everything outside of the focus of attention needs to be retrieved for processing; nevertheless, a set of representations, such as the most recently perceived items in non-focal state, may be temporarily more accessible due to a momentarily heightened level of activation (Jonides et al., 2008). Neural network models of verbal working memory suggest that these activated representations outside of the focus undergo trace decay (Jones & Polk, 2002; Lansner, Marklund, Sikström, & Nilsson, 2013). Accordingly, temporal decay in activation levels, together with similarity-based interference, are among the main factors that have been proposed to affect information retrieval during language comprehension: memory representations are assumed to receive activation boosts at moments of retrieval or when items with similar features are accessed, and these enhanced states of activation are followed by rapid time-based decay (Lewis & Vasishth, 2005; Vasishth & Lewis, 2006). Thus, the notion of temporal constraints on integration processes during language comprehension is compatible with unitary conceptions of memory since such limitations may derive from the fading of representations constituting the most recently perceived items that have been removed from a focal state. A 2–3 s long time