

Research Report

WORKING MEMORY CAPACITY DISSOCIATES LEXICAL AND SENTENTIAL CONTEXT EFFECTS

Cyma Van Petten,¹ Jill Weckerly,² Heather K. McIsaac,³ and Marta Kutas²

¹University of Arizona, ²University of California, San Diego, and ³University of British Columbia

Abstract—Semantically associated and unassociated word pairs were embedded in normal meaningful sentences and in sentences that were semantically anomalous throughout. The influence of lexical context was isolated via comparison of responses to the second words of the associated and unassociated pairs. The influence of sentence-level context was isolated by comparing responses to the same words in the two sentence types. Subjects of high, medium and low working memory capacity (as evaluated by the reading span test) showed modulations of event-related brain potentials in response to lexical context. In contrast, only the high- and medium-capacity groups were responsive to purely sentence-level semantic context. The results demonstrate that sentential context influences the processing of words in intermediate sentence positions at normal reading speeds but that the on-line utilization of this context is more demanding of working memory than single-word contexts.

Hundreds of laboratory studies indicate that pairs of words like *hot-cold* and *salt-pepper* are easier to process than unrelated pairs, as gauged by higher accuracies and shorter reaction times in a variety of tasks (Neely, 1991). Slightly fewer studies indicate that words are easier to process in coherent than incoherent sentences (Simpson, 1991). Explaining why both single-word (lexical) and sentence contexts should yield similar results has been a nagging problem in psycholinguistics. The most frequently cited explanation of lexical context effects is *automatic spreading activation* from the representation of one word to the representations of associated words in long-term memory (Collins & Loftus, 1975). The existence of this mechanism has been questioned (Ratcliff & McKoon, 1988), but whether or not spreading activation is a viable mechanism for lexical context effects, it clearly cannot account for sentence-level context effects. Because the number of meaningful sentences in any natural language is infinite, they cannot have stored representations. Some theorists have therefore concluded that lexical and sentence-level context effects emerge from fundamentally different mechanisms: a fast, automatic one and a slow, optional route (Fodor, 1983; Forster, 1981; Till, Moss, & Kintsch, 1988).

Although dozens of studies have demonstrated the influence of sentence-level context, null effects in other studies have convinced some investigators that its impact in normal reading is negligible. Instead, they have argued that such effects are restricted to laboratory situations which include final words that are highly predictable, are visually degraded, or occur at unnaturally long delays, often within tasks that encourage complex decision strategies (Fischler & Bloom, 1979; Henderson, 1982; Mitchell & Green, 1978; Stanovich & West, 1979). A second argument is that putative sentential effects can be attributed to lexical priming because one or more words in the sen-

tence are associated with the final word (Duffy, Henderson, & Morris, 1989).

The robustness of lexical context effects across a variety of paradigms and measures and the apparent fragility of sentential context effects may reflect a quantitative rather than qualitative difference. The time and effort required to make contextual information available are greater for a series of words (sentential) than for a single word (lexical). However, once available, lexical and sentential context may have similar influences on the processing of subsequent words.

Many facets of sentence comprehension—parsing, anaphor resolution, assigning thematic roles, and semantic integration—place demands on working memory. Although working memory is a convenient general term, a number of investigators have proposed distinct (although interrelated) working memory systems (Barnard, 1985; Gathercole & Baddeley, 1993; Martin, Shelton, & Yaffee, 1994; Shallice, 1988; Wilson, O'Scalaidhe, & Goldman-Rakic, 1993). The work of Carpenter, Just, and their colleagues has stressed the importance of at least one working memory system in sentence comprehension. The measure of working memory capacity developed in their laboratory requires a subject to retain (for subsequent verbal report) the final words of a set of sentences as he or she reads them aloud (Daneman & Carpenter, 1980). The *reading span* measure is thus designed to produce a conflict between the computational demands imposed by reading and the passive storage of information. Compared with subjects with low reading spans, subjects with higher spans perform better on a number of indices of reading comprehension (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Daneman & Green, 1986; Miyake, Just, & Carpenter, 1994; Whitney, Richie, & Clark, 1991).

The relationship between working memory capacity and language comprehension suggests that the ephemeral nature of sentence-level context effects may be due to variability among subject samples. The present study compared lexical and sentential context effects in subjects with different working memory capacities as measured by reading span. We used the event-related brain potential (ERP) as the dependent measure of the context effects. The use of an ERP measure allowed us to observe the processing of sentence-intermediate words without the interruption of normal comprehension processes required by a secondary task. We predicted that group differences would emerge in the use of sentence-level but not lexical context.

The N400 component of the ERP (a negative wave peaking at about 400 ms after the onset of a visually presented word) is a sensitive metric of semantic context in word pair, word list, and sentence paradigms (see Kutas & Van Petten, 1994, for review). Words that are congruent with a preceding sentence context or related to a single prior word elicit smaller N400s than incongruent or unrelated words. Moreover, words that occur late in congruent sentences elicit smaller N400s than words that occur earlier because they can benefit from a larger chunk of the ongoing sentence context. In contrast, the amplitude of the N400 elicited in random word strings or in syntactically legal but semantically incoherent sentences does not vary as a function of position in the sentence (Van Petten, 1993). N400s to words

Address correspondence to Cyma Van Petten, Department of Psychology, University of Arizona, Tucson, AZ 85721, e-mail: vanpett@convx1.ccit.arizona.edu

occurring early in congruent sentences are thus equivalent to N400s to words at any point in meaningless sentences. This pattern of results suggests that a large N400 is the default response rather than just an index of incongruity, this default response declines as semantic context becomes available from the preceding stimuli.

METHOD

The subjects were 45 native English speakers (students or staff at the University of California, San Diego) who gave informed consent. Fifteen were classified as "low span" because they could not reliably recall the final words of three sentences after having read them aloud (mean span = 2.26, mean age = 23.6 years, 7 women), 15 were "medium span" because they could recall final words from sets of three, but not four, sentences (mean span = 3.0, mean age = 21.3 years, 7 women), and 15 were classified as "high span" (mean span = 4.0, mean age = 19.8 years, 8 women). One high- and 1 low-span subject were left-handed, 4 of the medium- and 3 of the low-span group reported having left-handed parents or siblings.

Each subject read 480 sentences like those in Table 1 (60 sentences in each condition during each of two sessions, randomly intermixed). Each sentence contained a critical pair of words. In the *congruent-associated* condition, the two critical words were embedded in a meaningful sentence, but were also related to each other independent of the sentence context. The second word could therefore benefit from the overall sentence context, as well as from its lexical-associative relationship to the first word. In the *anomalous-associated* condition, the same word pairs were embedded in syntactically legal but semantically anomalous sentences. In this condition, the second critical word could benefit only from the preceding lexical associate. In the *congruent-unassociated* condition, the critical words were related only via the general sentence context. In the *anomalous-unassociated* condition, the same words served as a no-context control. Across the four conditions, the critical word pairs were matched for length, frequency of usage, and positions within their sentences. The stimuli were counterbalanced across two sessions so that each critical word pair was seen only once in each session (sessions were conducted at

least a week apart), but each pair was presented in both a congruent and an anomalous sentence. The subset of pairs presented in the first versus second session was counterbalanced across subjects. In a previous study, we found that the second words of the critical pairs elicited smaller N400s than the first words in all three conditions that provided any semantic context, but identical N400s in the anomalous-unassociated sentences (Van Petten, 1993). This finding offers reassurance that the unassociated words were indeed unassociated.

The sentences averaged 14.2 words (range 8–22). Anomalous sentences were formed by replacing open-class words in the congruent sentences with other words of the same form class (e.g., nouns, verbs, adjectives other than quantifiers, -ly adverbs). The replacements were drawn from the pool of open-class words used in the congruent sentences, so that the same set of words occurred in both the congruent and anomalous sentence types. The sentences were presented one word at a time on a computer monitor, at a rate of one word every 300 ms—significantly faster than in previous ERP studies of sentence processing, which have been criticized for encouraging unnatural reading strategies induced by a slow presentation rate (see Garnsey, 1993).

Subjects were asked to read for comprehension, and also to indicate with a button-press whether or not a single word presented 1.5 s after each sentence had occurred in the sentence. The probe recognition task was designed to keep subjects alert, the critical words were never used as targets. No responses were required while reading. Because the probe recognition task is *de facto* a working memory task, we expected low-span subjects to show the lowest recognition accuracy. Moreover, in a previous study using the same sentence materials presented at a slower rate (one word every 600 ms), probe recognition performance was positively correlated with sentence-level context effects (Van Petten, 1993).

Each subject was fitted with an elastic cap with 12 electrodes covering most of the scalp. In addition, two channels were used for monitoring vertical and horizontal eye movements, trials contaminated by electroocular artifacts were excluded from the analysis. The reference was the averaged activity from the left and right mastoids. The bandpass was 0.01 to 100 Hz at a sampling rate of 250 Hz.

RESULTS

Accuracies in the probe recognition task averaged 91.8%, but the low-span group performed slightly worse (89.5%) than the high- or medium-span groups (both 92%), $F(2, 42) = 5.49, p < .01$.

N400 amplitudes were quantified as mean voltages in the 300- to 500-ms latency window (relative to a 100-ms prestimulus baseline) and subjected to an initial analysis of variance taking span, congruity (congruent vs anomalous), association (associated vs unassociated words), and electrode site (12 levels) as factors. Both sentence congruity and lexical association reduced N400 amplitude, $F_s(1, 42) = 56.2$ and $48.9, p_s < .0001$. Congruent-associated words elicited smaller N400s than the critical words in the other three conditions, $\text{Congruity} \times \text{Association } F(1, 42) = 7.94, p < .01$. The impact of sentence congruity was modulated by reading span, $\text{Span} \times \text{Congruity } F(2, 42) = 6.63, p < .005$. The influence of lexical association was not dependent on reading span, $\text{Span} \times \text{Association } F < 1$. Next, we examine the sentential and lexical effects in turn, first for all the subjects, then as a function of reading span.

Table 1 Examples of the four sentence types

Type	Example
Congruent-associated	When the moon is full it is hard to see many stars or the Milky Way
Congruent-unassociated	When the insurance investigators found that he'd been drinking they refused to pay the claim
Anomalous-associated	When the moon is rusted it is available to buy many stars or the Santa Ana
Anomalous-unassociated	When the insurance supplies explained that he'd been complaining they refused to speak the keys

Note: The critical pairs of words are shown in bold.

Lexical and Sentence-Level Context

Sentence-Level Context

The experimental design allowed for two measures of sentential context derived by comparing responses to the same words embedded in semantically congruent versus anomalous sentences. The left side of Figure 1 shows that associated words (e.g., *pepper* preceded by *salt*) elicited smaller N400s when they were embedded in congruent than anomalous sentences, $F(1, 44) = 38.8, p < .0001$. At this rapid presentation rate, the ERPs elicited by sentence-intermediate words are a nearly sinusoidal series of negative and positive peaks rather than the more complex sequence of components observed at slower rates. However, the influence of sentence congruity is much like that obtained at slower rates: more positive waveforms beginning at about 250 ms poststimulus onset, peaking at 400 ms, and continuing to at least 700 ms. The sentential context effect was not dependent on lexical association, but also occurred when the critical second word was not strongly related to any prior word in the sentence, $F(1, 44) = 18.9, p < .0001$.

Lexical Context

Semantic relationships at the single-word level were likewise evident in the ERP. Within otherwise anomalous sentences, words preceded by a lexical associate elicited smaller N400s than unassociated control words, $F(1, 44) = 20.4, p < .0001$. Because some studies have suggested that lexical context effects are short-lived (Foss, 1982; Simpson, Peterson, Casteel, & Burgess, 1989), we subdivided the associated pairs into *close* versus *distant*. Approximately half (59/120) of the pairs in each condition were immediately adjacent or separated by one intervening word, the remainder were separated by an average of 4.8 intervening words. The left side of Figure 2 shows

that only nearby associates were effective in reducing N400 amplitude. A comparison of associated and unassociated words in anomalous sentences was significant for close pairs, $F(1, 44) = 17.8, p < .0001$, but null for distant pairs, $F(1, 44) = 2.31$. In contrast, the right side of Figure 2 shows that the purely sentential context effect was more evident for the second words of distant pairs. These occurred later in the sentences and could thus benefit from a larger amount of sentence context than the second words of close pairs. A comparison between the congruent-unassociated and anomalous-unassociated conditions was significant for distant pairs, $F(1, 44) = 24.4, p < .0001$, but not for close pairs, $F(1, 44) = 2.92$.

Influence of Working Memory Capacity

Table 2 shows that the purely lexical context effect (anomalous-associated vs. anomalous-unassociated) was independently significant for the high-, medium-, and low-span groups. An analysis of variance including all three groups revealed no group interaction, $F(2, 42) = 2.14$. All three groups also showed an influence of sentential context, but only when the sentence-level relationships were bolstered by lexical association. Although the low-span readers exhibited smaller N400s for associated words in congruent than anomalous sentences, the high- and medium-span groups derived greater benefit from the combination of sentential and lexical context, $F(2, 42) = 3.40, p < .05$. In the absence of lexical associations, a sentential context effect was evident in only the high- and medium-span groups, as seen in

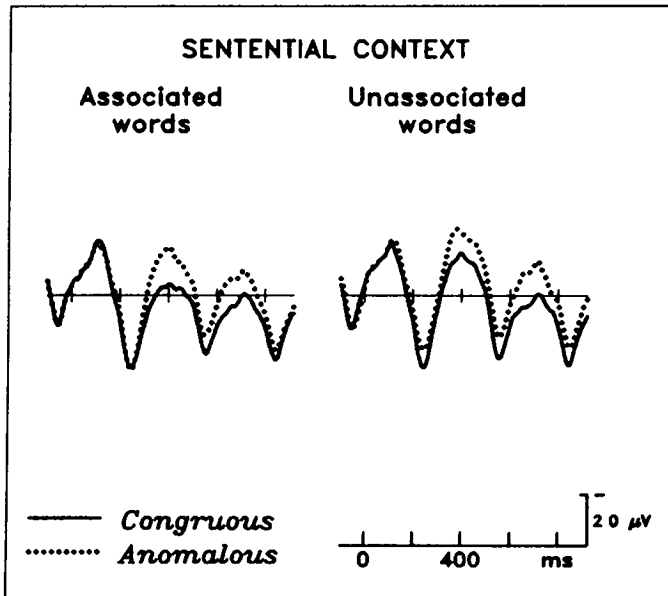


Fig. 1. Event-related potentials elicited by the second words of the critical pairs, across all subjects. On the left is a contrast between the congruent-associated and anomalous-associated conditions. On the right is a contrast between the congruent-unassociated and anomalous-unassociated conditions. All responses were recorded from the Cz electrode site located at the vertex of the scalp.

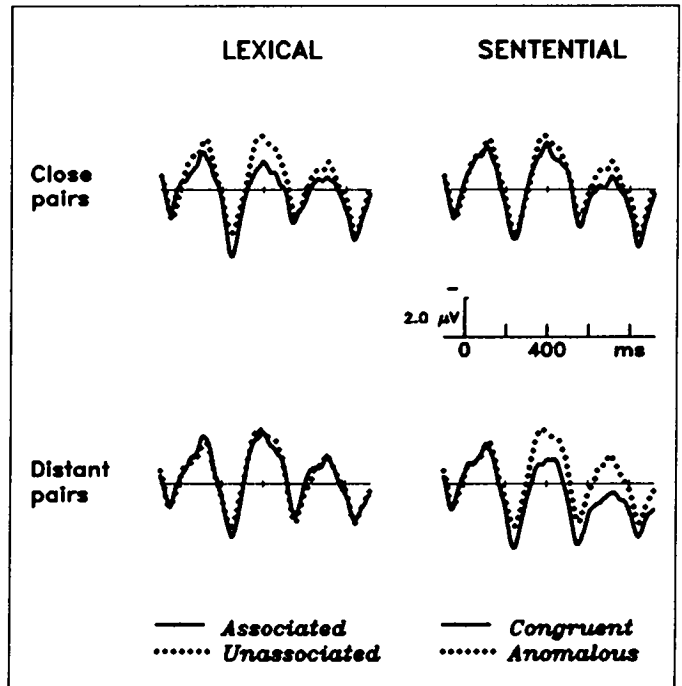


Fig. 2. Event-related potentials elicited by the second words of the critical pairs, as a function of the distance between the paired words. The left column shows the influence of purely lexical context (anomalous-associated condition vs. anomalous-unassociated condition). The right column shows the influence of purely sentential context (congruent-unassociated condition vs. anomalous-unassociated condition). The waveforms are grand averages across all subjects, recorded from site Cz.

Table 2 Statistical analyses of context effects in the three reading span groups

Effect	Group		
	High span	Medium span	Low span
	300- to 500-ms latency window		
Lexical (AA vs AU)	12.4** (1.79)	5.23* (3.50)	10.1** (3.86)
Sentential, with associated words (CA vs AA)	6.75* (5.37)	48.1**** (2.83)	6.73* (4.12)
Sentential, without associated words (CU vs AU)	12.9** (3.35)	6.85* (5.62)	0.37 (4.53)
	500- to 700-ms latency window		
Lexical (AA vs AU)	0.07 (3.62)	0.31 (2.44)	2.87 (2.47)
Sentential, with associated words (CA vs AA)	9.9** (7.60)	28.0*** (3.79)	0.03 (4.82)
Sentential, without associated words (CU vs AU)	4.9* (4.42)	7.5* (8.51)	1.06 (3.78)

Note Listed are *F* values (*df* = 1, 14) for pair-wise comparisons within each span group. Numbers in parentheses are *MSEs*. Abbreviations for the conditions compared are as follows: AA = anomalous-associated; AU = anomalous-unassociated; CA = congruent-associated; CU = congruent-unassociated.

p* < .05 *p* < .01 ****p* < .001 *****p* < .0001

Figure 3 A comparison of the congruent-unassociated and anomalous-unassociated conditions thus included a Span × Congruity interaction, $F(2, 42) = 3.28, p < .05$

We have focused on analyses of the 300- to 500-ms latency window because this captures the peak of the N400. However, Table 2 shows that the sentence-level context effects continue beyond 500 ms poststimulus onset. Analyses of a 500- to 700-ms latency window were similar to those of the earlier time frame in showing sentential effects in the high- and medium-span groups only. The lexical context effect was of shorter duration, and did not extend into the later time window for any reading span group (see also Van Petten, 1993).

DISCUSSION

The central findings of the experiment are that sentence-level context can influence the processing of sentence-intermediate words at normal reading rates, but that readers with low working memory capacity are less efficient than readers with greater working memory capacity in making this context available for use.¹ Given that low-span subjects tend to fare poorly on several indices of reading comprehension, there is an apparent conflict between these results

1 It can be argued that the use of a probe recognition task exaggerated the group difference in sentence-level context effects. The low-span readers may have diverted limited working memory resources to remembering single words at the expense of building sentence-level interpretations. Comparisons across span groups with a sentence-level behavioral task are worth future investigation. However, the study most comparable to the one reported here observed group differences in the absence of a word-level recognition task. In that study paragraphs were completed with an inference that could be drawn from the preceding material. Low-span readers generated larger N400s than high-span readers for elaborative, but not bridging inferences (St. George-Hoffman, & Mannes, 1995).

and reports that poor readers show semantic context effects as large as or larger than those of good readers (Perfetti & Roth, 1981; Stanovich, Cunningham, & Feeman, 1984). However, few studies have differentiated lexical from sentence-level context when evaluating readers of different skill levels. Associative relationships between single words develop from repeated co-occurrences over time, and do not require the formation of new conceptual combinations in working memory. The low-span readers in the present experiment did not differ from the high- or medium-span groups in their appreciation of these lexical-associative relationships. The results also suggest that low-span readers were able to use strong lexical relationships to help build sentence-level interpretations, because the brain activity elicited by associated words differed between the congruent and anomalous sentences. It was only when the meaning of a sentence could not rely on previously established associations that the low-span readers proved deficient in the use of context.

The distinction between lexical and sentential context drawn here is consistent with the results of a study investigating the flexibility of semantic encoding in good and poor readers. Merrill, Sperber, and McCauley (1981) compared color-naming latencies for targets that were related or unrelated to sentence-final words. Good readers were slowed by semantic relationships only when the target was relevant to the global context of the preceding sentence (e.g., for "fur" after "The girl touched the cat," but for "claw" after "The girl fought the cat"). Poor readers showed interference for all related targets, regardless of the overall meaning of the sentence.

Gernsbacher and Robertson (1995) have argued similarly that the inability to suppress irrelevant or inappropriate associations is diagnostic of the poor comprehender. It is important to note, however, that the subjects in the current study were selected not for their comprehension ability, but instead on the basis of one factor likely to

Lexical and Sentence-Level Context

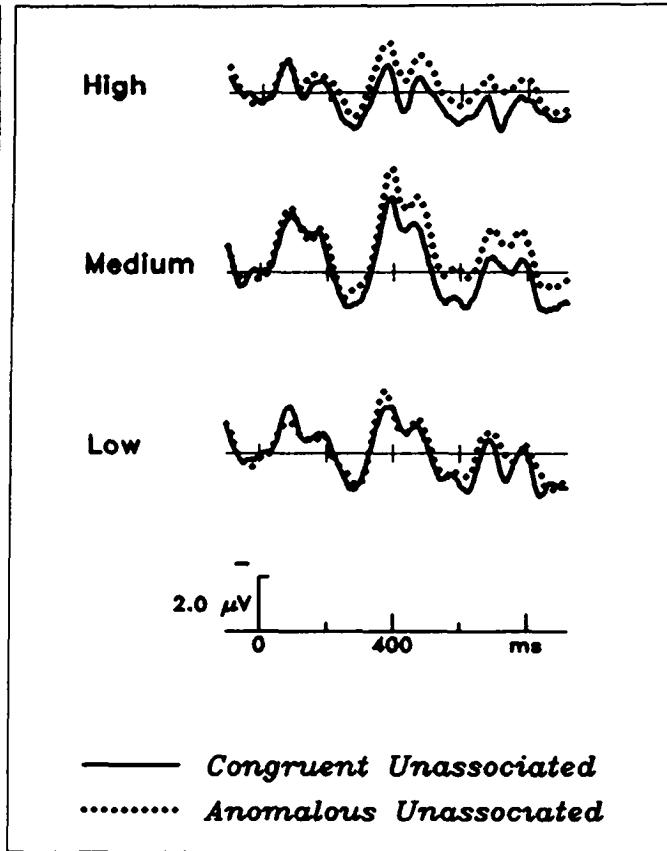


Fig. 3 Grand average event-related potentials showing the effect of purely sentential context for the three reading span groups. These responses for the second words of the critical pairs in congruent-unassociated versus anomalous-unassociated sentences were recorded from a right temporo-parietal site.

underlie this ability, working memory capacity. A challenge for further research will be to describe the nature and number of the working memory operations involved in creating a sentence-level interpretation that can facilitate the processing of subsequent words. In the meantime, the observation that a sentence-level context effect varies with individual working memory capacity helps to reconcile some earlier disputes about the very possibility of utilizing context beyond the single-word level.

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