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Words and sentences: Event-related brain potential measures

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Abstract

Interactions between sentences and the individual words that comprise them are reviewed in studies using the event-related brain potential (ERP). Results suggest that, for ambiguous words preceded by a biasing sentence context, context is used at an early stage to constrain the relevant sense of a word rather than select among multiple active senses. A study comparing associative single-word context and sentence-level context also suggests that sentence context influences the earliest stage of semantic analysis, but that the ability to use sentence context effectively is more demanding of working memory than the ability to use single-word contexts. Another indication that sentence context has a dramatic effect on single-word processing was the observation that high- and low-frequency words elicit different ERPs at the beginnings of sentences but that this effect is suppressed by a meaningful sentence context.

Descriptors: Event-related potential, N400, Semantic context, Sentence processing, Word frequency, Ambiguity

Language is marked by part–whole relationships at many levels: letters or phonemes make up words, words make up sentences, and sentences make up discourse. Some basic questions in psycholinguistics concern how these part–whole relationships map onto the human system for processing language. Research over the last century has suggested that neither comprehension nor production proceed in a strictly serial fashion from the simplest to the most complex units. Instead, both introspection and empirical measures demonstrate a multitude of context effects wherein higher-level units apparently influence the perception, production, or speed of analyzing lower units. In production,

such context effects include the coarticulation of adjacent phonemes, so that the pronunciation of any given consonant or vowel will depend on the preceding and following phonemes. In speech perception, the same acoustic signal can be perceived as different phonemes depending on the speaker and his or her rate of speech; listeners normally adjust for these sources of variability by integrating information across more than one phoneme (for review, see Handel, 1989). For these context effects in speech perception and production, the relevant units seem to be phonemes and syllables. Other context effects can only be explained by granting that whole words are an important unit. In the auditory modality, a well-studied phenomenon is the phoneme restoration effect, wherein listeners claim to hear all of a word although one phoneme has been replaced with a cough or white noise (Warren, 1970). Analogous context effects occur for the orthographic pattern of written words. A character such as A might be reported as an "H" in "THE," but as an "A" in "CAT." Even for stimuli consisting of well-formed letters, word superiority effects indicate that whole words can be easier to perceive than isolated letters (Cattell, 1885, 1886; cited and discussed in Henderson, 1982).

The studies reviewed here investigate context effects that involve meaning and that operate at the level of interactions between sentences and words. Semantic context effects have stimulated a great deal of research, beginning with reports in the 1960s and 1970s that words which form a congruous completion to a sentence fragment are more likely to be identified with brief exposure durations and receive faster responses in a vari-

ety of tasks than incongruous completions (e.g., Fischler & Bloom, 1979; Tulving, Mandler, & Baumal, 1964). Although event-related potentials (ERPs) came into widespread use at about the same time that language comprehension became (again) a respectable research topic, initial attempts to apply ERPs to the study of language processing were discouraging (e.g., see the conclusions of Donchin, McCarthy & Kutas, 1977; Galambos, Benson, Smith, Schulman-Galambos, & Osier, 1975). In contrast, research over the last 15 years has demonstrated that ERPs are a useful tool for the study of language processing. A great deal of our current confidence that ERPs elicited by linguistic stimuli are informative can be credited to a simple change in research strategy: investigators turned away from the requirement that the stimuli used to elicit ERPs in different conditions be physically identical; instead, they formed averaged ERPs from sets of stimuli that were physically diverse but conceptually similar. This research strategy led Kutas and Hillyard (1980a) to compare words that did and did not fit with an established semantic context. Their report that semantic context influenced a late negative component of the ERP, the N400, instilled new optimism that the ERP methodology could provide online, unobtrusive measures of language processing (for reviews of some of the many studies in the last 15 years, see Kutas & Van Petten, 1988, 1994).

The studies reviewed here focus on contextual interactions between sentences and the individual words that comprise them. Our intuition suggests that individual words can have vague, broad, or ambiguous meanings and that these are sharpened by our sense of what the speaker or writer is trying to convey. But the paradox remains that individual words are used to arrive at a sentence meaning, and yet overall sentence meaning determines the meaning of individual words. Views range from those of Schank (1978), who wrote "Analysis proceeds in a top–down predictive manner. Understanding is expectation based. It is only when the expectations are useless or wrong that bottom-up processing begins" (p. 94), to Kintsch and Mross (1985), who wrote "What readers say they expect at a certain place in a certain text has no effect on sense activation, or in other words, there are no top–down effects of thematic context on the sense activation phase of word identification" (p. 346). In recent years, the dominant view has more closely resembled that expressed by Kintsch and Mross (1985): the early phases of semantic analysis are insensitive to sentence or discourse context. For instance, one influential model supposes that word- and sentence-level analyses take place in distinct modular components of the language-processing system and that communication between them occurs in only one direction: from word to sentence (Fodor, 1983; Forster, 1979, 1981; Garrett, 1990). There may be stages of visual word recognition that precede any semantic analysis, as suggested by recent intracranial ERP recordings (McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre & McCarthy, 1995; Nobre, Allison, & McCarthy, 1994), but the studies reviewed here suggest that sentence context modifies and permeates many aspects of the processing of single words.

Sentence Constraints on Ambiguous Words

My first sentence study used a paradigm considered to be definitive for isolating lexical from sentence-level semantics. Most English words have many subtly different senses, which may or may not be highlighted in different contexts, but a few are considered "ambiguous" because they possess at least two meanings that are unrelated to one another. Although we are not usually aware of the irrelevant meanings of homographic or homophonic words, Conrad (1974) was the first to reason that activation of these senses might be detected in a semantic priming paradigm. She presented auditory sentences ending with a homophonous word, followed by a word printed in colored ink. Color-naming times were slower for words related to either sense of the homophone than for completely unrelated words. The interpretation of this Stroop interference was that both meanings of the homophone were active enough to prime their semantic associates and make it more difficult to suppress those associates in favor of their ink colors. Conrad's observation was replicated (Oden & Spira, 1983) and followed by many studies using lexical decision or pronunciation latencies to measure priming of relevant and irrelevant associates of homographic or homophonous words that had been disambiguated by a sentence context (Blutner & Sommer, 1988; Kintsch & Mross, 1985; Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Lieman, & Bienkowski, 1982; Swinney, 1979; Till, Mross, & Kintsch, 1988; also see review by Simpson, 1994). These studies manipulated the temporal interval between the ambiguous and probe words and found that a short interval yielded priming for both relevant and irrelevant associates, whereas a long interval yielded priming for only the contextually relevant target. These investigators thus converged on a two-stage model of semantic processing: (a) single words quickly and automatically activate all of their possible meanings, which in turn activate the meanings of their lexical associates; but (b) a slower-acting sentence processor selects the relevant meaning of each word and allows the irrelevant activations to fade. Onifer and Swinney (1981) described this model most succinctly:

By this hypothesis, when an ambiguity (or any word) is encountered, all of its senses or meanings are at least momentarily made available to the comprehension device. ...Lexical access is viewed as being an isolable subprocess in the comprehension routine, one that operates in a bottom-up fashion based entirely on the (acoustic/phonetic) form of the word. The effects of contextual constraints are seen to operate on the accessed candidates in a subsequent, independent process. (p. 227)

A more recent (and still a minority) view argues that a sentence context of appropriate strength and nature can constrain initial meaning access (Kellas, Paul, Martin, & Simpson, 1991; Paul, Kellas, Martin, & Clark, 1992; Simpson & Kreuger, 1991; Tabossi, 1988; Tabossi & Zardon, 1993). Nonetheless, many textbooks offer lexical ambiguity research as a premier example of the failure of sentence processing to influence the initial stages of semantic analysis (Carroll, 1994; Garrett, 1990).

The claim that there are two discrete stages of semantic analysis is well suited to an evaluation with ERPs because these offer a continuous record of brain activity beginning at stimulus onset. We constructed a set of 120 sentences ending with homographs, together with an equal number ending in non-homographic words (Van Petten & Kutas, 1987a). Each homograph sentence was followed by one of three types of probe words—contextually relevant, contextually irrelevant, or unrelated, as shown in Table 1. The sentences biased the less common, subordinate, sense of each homograph so that the contextually relevant probe word was related to the subordinate meaning. The sentences were presented visually, one word at a time, with a duration of 200 ms per word. The probe words were presented immediately at the offset of the final sentence word (200 ms stimulus onset asynchrony [SOA]) or 500 ms later (700 ms SOA) in separate groups of subjects.

Table 1. *Examples of the Lexical Ambiguity Stimuli[a]*

	Contextually relevant	Contextually irrelevant	Unrelated
Homograph sentences, subordinant			
He was not used to hard labor and soon began to tire.	sleep	wheel	rifle
The protestors wanted to shut down the nuclear power plant.	factory	green	mouth
When the judge entered the courtroom the audience all rose.	stood	flower	fashion
Homograph sentences, dominant			
The old car had a flat tire.	wheel	sleep	rifle
While she was away her next door neighbor fed the cats and watered the house plants.	factories	green	mouth
The florist gave his wife a single red rose.	flower	stood	fashion
Nonhomograph sentences			
His uncle wanted to know why he hadn't settled down and gotten married.	single	—	trade
She let the phone ring six times but there was no answer.	question	—	room

[a]The first ambiguity experiment described in the text (Van Petten & Kutas, 1987a) used sentences biasing the subordinant meaning of homographs. The second experiment (unpublished) used sentences biasing the dominant meaning. Both used an equal number of sentences ending with unambiguous words.

We first verified that the stimulus set was adequate by recording pronunciation latencies to the probe words. The behavioral data in the short SOA condition replicated the "multiple access" phenomenon in showing faster reaction times (RTs) for both relevant and irrelevant probe words versus the unrelated probes. At the longer SOA, irrelevant probes were responded to as slowly as unrelated words. The ERP version of the experiment was nearly identical to the reaction time version, except that we eliminated the naming task to avoid artifacts from muscle activity and tongue movements. To ensure that subjects read the probe words, we presented a single letter 1.5 s later and asked them to indicate whether or not the letter was in the probe word. This task delays any binary decisions until well beyond the probe word so that N400 latencies can be measured without the complication of overlapping decision-related P300s (see Kutas & Hillyard, 1989).

The ERP results are shown in Figure 1. With a long SOA (700 ms), the ERPs elicited by the sentence-final and probe words can be distinguished clearly from each other. There were no differences among the ERPs elicited by the sentence-final words, so the long SOA condition did not suggest that any special processing was accorded to the homographs as compared with the unambiguous final words. ERPs to the probe words did vary according to their semantic relationship to the sentence-final word. The unrelated probe words elicited larger N400s than contextually relevant probes following both homograph and nonhomograph sentences. The contextually irrelevant probes also elicited large N400s, which were indistinguishable from unrelated probes. The N400 differences had typical onset and peak latencies for words in pairs, beginning about 300 ms after stimulus onset and peaking at about 500 ms poststimulus. Even the two-stage model of semantic processing would predict this pattern of results, but the long SOA data indicate that if our subjects had a delayed realization that the irrelevant probe was related to the homograph, it was not reflected in the N400.

The ERPs recorded in the short SOA condition are different in waveshape from those observed with a longer SOA. At minimum, the ERPs elicited by the sentence-final and probe words are subject to temporal overlap and superimposition, but it is also possible that the waveform reflects a cognitive process not present in the long SOA condition, that is, processing two words at the same time. In either case, the influence of seman-

tic relationship for the nonhomograph conditions was similar to that observed at the longer SOA: a monophasic negative difference between related and unrelated probes beginning at 300 ms poststimulus. In the homograph conditions, the difference between contextually relevant and completely unrelated
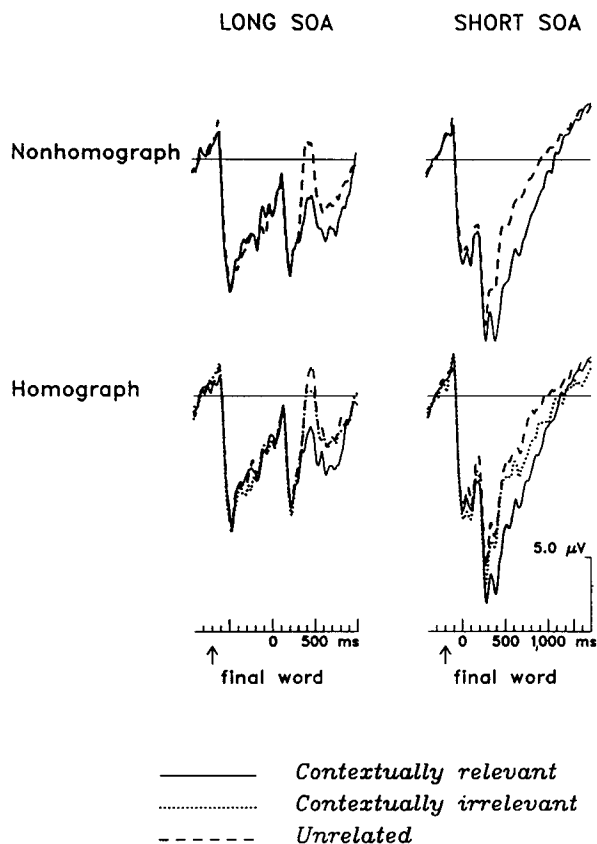

Figure 1. Grand average ERPs from site Cz. Fifteen subjects were in the long SOA group, and 18 were in the short SOA group. Time 0 marks the onset of probe words following sentences that end with homographic or nonhomographic words. Onset of the sentence-final words is marked by the arrow (data from Van Petten & Kutas, 1987a).

probes was much like the semantic context effect in the non-homograph conditions.

As in the RT data, the short temporal interval yielded a difference between the contextually irrelevant and unrelated probes that was not observed with a long SOA. Beginning at about 500 ms after the probe word's onset, the ERPs elicited by the irrelevant probes are distinct from those to the unrelated words. However, this difference began well after the basic N400 semantic context effect. Both the unrelated and irrelevant probe ERPs diverge from the related ERP at about 300 ms poststimulus and are initially indistinguishable. It is only around 500 ms poststimulus that the response to irrelevant probes begins to resemble that of the contextually relevant probes. These results demonstrate that irrelevant probes are subject to a semantic context effect under this set of conditions but that priming for these words lags behind that for contextually relevant words. Even the delayed ERP context effect was, however, earlier than the RTs recorded in the behavioral portion of this study.

The results of this ambiguity study are not compatible with the "multiple-access" theory that all meanings of a word are activated simultaneously regardless of sentence context. The RT and ERP measures were both sensitive to the temporal interval between homograph and probe word: neither showed a priming effect for irrelevant probes at the long SOA, and both showed context effects at the short SOA. The ERP data, however, provided a more detailed picture of the time course of the context effects for relevant and irrelevant probes at the short SOA. Although both occurred early enough to affect overt behavior, the shorter onset latency for relevant probe words indicated an early influence of sentence context. The multiple access model predicted that, indeed, there are two temporally ordered phases of semantic analysis and two corresponding phases of context effect, but that sentential context influences only the late phase. The ERP latencies yielded the opposite pattern of results in suggesting that the meaning of a sentence constrained the earliest observable effect of semantic analysis.

But what accounts for the delayed N400 effect elicited by irrelevant probe words? The logic of the ambiguity paradigm is that the probe words serve as a tool for evaluating how subjects interpreted the preceding ambiguous word: if the probe word shows a priming effect, it can only be due to the prior interpretation of the ambiguous word. This logic can be challenged, however; perhaps the actual presentation of an irrelevant probe word activates the otherwise dormant meaning of the homograph. It may be counterintuitive to imagine that a probe word presented later could influence the meaning of the homograph. But all we need to assume is that analyzing a word's meaning is not instantaneous but rather a process that unfolds over time. Other experimental results have shown that reaction time and accuracy to respond to one word can be influenced by presenting a related word a short time later (Dark, 1988; Den Heyer, Briand, & Dannenbring, 1988; Kiger & Glass, 1983; Peterson & Simpson, 1989; Van Petten & Kutas, 1991b). This phenomenon has been called "backward" or "retroactive" priming, but we prefer to think of it as "mutual" priming. If two words are presented in close temporal conjunction, their processing is likely to overlap in time, and both words may benefit from this overlap if they are related. In the classic ambiguity paradigm, the preceding sentence context may provide an effective and constraining source of context for one reading of the ambiguous word. But while processing of the ambiguity is incomplete, the alternate meaning and its associated probe word can

also form a related pair. The observed lag between the two ERP context effects may thus reflect the temporal lag between the presentation of the prior sentence context and the subsequent probe word context. The mutual priming account suggests that multiple access to both meanings of ambiguous words does occur but that it is an artifact of the laboratory paradigm rather than the natural state of affairs for words in context.

We performed a second experiment to test a possible alternative to the mutual priming account (Van Petten & Kutas, 1987b). As an alternative to the strong multiple access or selective access models, one can take an intermediate position that semantic activation is determined by an interplay between sentence context and the frequency of an ambiguous word's meaning (Kellas et al., 1991; Simpson, 1981; Simpson & Burgess, 1985). Most ambiguous words have a dominant and a subordinant sense when presented in isolation. Because the contextually irrelevant probes in the first experiment were related to the more dominant meaning, it is possible that the long-latency ERP context reflected a delayed, but obligatory, activation of this more common meaning. To test this possibility, we constructed a new set of sentences with the same homographic words, but now biasing the opposite, dominant, meaning of each homograph as shown in Table 1. If the late N400 context effect for irrelevant probes reflected obligatory access to a homograph's dominant meaning, then relating the irrelevant probes to the subordinant meaning should eliminate this effect. Alternatively, if the longer-latency ERP context effect were due to mutual priming between the homographs and irrelevant probe words, then the dominance manipulation should have no impact.

The general methodology for the second ambiguity experiment was much like the first; 18 subjects participated in the 200 ms SOA version and 21 in the 700 ms SOA version. The ERPs were visually similar to those observed in the first experiment. As seen in Figure 2, there was little difference between the irrelevant and unrelated probes when these were separated by 700 ms. With a short SOA, the ERP elicited by irrelevant probes was initially indistinguishable from that elicited by the unrelated words but became more similar to relevant probe ERP later in the epoch. However, the delayed context effect only approached statistical significance ($p = .065$) when evaluated by the same measurement and statistical procedures as used in the first experiment. The statistical pattern of results was otherwise identical to the first experiment in showing that the prior sentence context influenced the earliest phase of the N400. But because the second study was designed to evaluate the presence or absence of the delayed context effect for irrelevant probes, the outcome was not fully satisfactory.

The ambivalent outcome of the second experiment may have been due to a methodological flaw in the stimulus construction. In the first experiment, the sentences provided a strong bias for the interpretation of the homographic final words but were only moderately predictive of the identity of the final word. Predictability was measured in an offline cloze probability test wherein pilot subjects were given the sentences without the final words and asked to fill in "the best completion" of each sentence; an average of 55% of the subjects chose the desired homographs. Given the sentence frames biasing the dominant meanings, the same homographs were much more predictable (mean cloze probability of 80%). If the ERP subjects were in fact predicting the sentence-final homographs before their actual appearance, the functional interval between the homographs and probe words would have been longer than the nominal SOA of 200 ms.
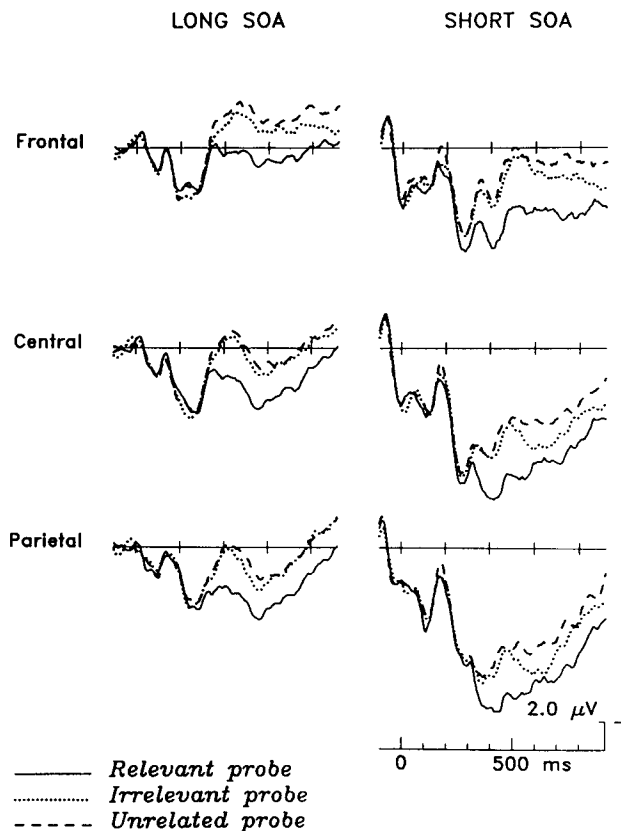
LONG SOA　　　　　SHORT SOA

Frontal

Central

Parietal

2.0 μV

———— *Relevant probe*
············· *Irrelevant probe*
- - - - - *Unrelated probe*

0　　　　500 ms

Figure 2. Grand average ERPs from Fz, Cz, and Pz. Eighteen subjects were in the long SOA group, and 21 were in the short SOA group. Time 0 marks the onset of probe words following sentences that end with homographic words (Van Petten & Kutas, 1987b).

Because the late context effect for irrelevant probes is only apparent when they are presented in close temporal proximity to the homographs, advance prediction of the homographs may have reduced the amount of temporal overlap in processing the homograph and probe words and weakened the late context effect.

The results of the two ambiguity experiments are in accord in indicating that the initial semantic processing of ambiguous words is guided by sentence context. This conclusion is inconsistent with the notion that there is a discrete stage of single-word semantic analysis independent of sentence context. Subsequent experiments, described below, explored other aspects of the interactions between single words and the sentences they comprise.

Influence of Sentence Context on Intermediate Words.

The initial experiments of Kutas and Hillyard (1980a, 1980b, 1980c, 1982) described the N400 effect as a difference between semantically congruent and anomalous sentence terminations. The terminal word congruity effect is robust and has been used as a tool to investigate differences between populations: monolinguals versus bilinguals (Ardal, Donald, Meuter, Muldrew, & Luce, 1990), children versus adults (Holcomb, Coffey, & Neville, 1992), young versus elderly adults (Gunter, Jackson, &

Mulder, 1992; Woodward, Ford, & Hammett, 1993), deaf versus hearing individuals (Neville, Mills, & Lawson, 1992), language-impaired versus normal children (Neville, Coffey, Holcomb, & Tallal, 1993), and schizophrenic versus control subjects (Adams, Faux, Nestor, & Shenton, 1993; Andrews et al., 1993; Mitchell, Andrews, Catts, Ward, & McConaghy, 1991). The N400 semantic congruity effect has also been used to make comparisons among informational modalities (written, spoken and signed language, pictures, environmental sounds: Connolly & Phillips, 1994; Connolly, Philips, Stewart, & Brake, 1992; Connolly, Stewart, & Phillips, 1990; Holcomb & Neville, 1991; Ganis, Kutas, & Sereno, in press; Kutas, Neville, & Holcomb, 1987; Kutas & Van Petten, 1990; Neville, 1991; Nigam, Hoffman, & Simons, 1992; Van Petten & Rheinfelder, 1995) and to explore some aspects of syntactic processing (Garnsey, Tanenhaus, & Chapman, 1989). Despite the utility of the experimental effect, detecting semantically anomalous sentence endings is unlikely to be a core factor in natural language processing. Shortly after their initial description of the N400, Kutas and Hillyard quickly demonstrated that it is not restricted to final words, nor does it depend on semantic incongruity. In the middle of sentences, incongruous words also elicit a much larger N400 than congruous words (Kutas & Hillyard, 1983). More importantly, the amplitude of the N400 elicited by congruous final words is a graded function of their predictability from the sentence context (Kutas & Hillyard, 1984; Kutas, Lindamood, & Hillyard, 1984). These results are more in line with the view that linguistic incongruities, errors, or violations are likely to be epiphenomenal and reducible to more fundamental properties of language and cognition, at least some of which can be studied with the ERP methodology (see Kutas & Kluender, 1994).

It was with this view in mind that we examined the ERPs elicited by congruous intermediate words as a function of their ordinal position in sentences. Simple ordinal position is also unlikely to be a core factor in language processing. But for sentences outside of discourse context, the reader can have no knowledge of the content of any given sentence at its outset and thus must build a mental representation only as the sentence progresses. We thus predicted that words occurring early in sentences would elicit larger N400s than words that could benefit from more context because they occurred later. This prediction was confirmed; for the sentence materials initially examined, the amplitude of the N400 declined as a nearly linear function of each word's position in its sentence (Kutas, Van Petten, & Besson, 1988; Van Petten & Kutas, 1990). The linearity of the function may be an artifact of averaging across syntactically heterogenous sentences. Clause boundaries often mark semantic shifts so that a more fine-grained analysis with structurally and semantically homogenous sentences might reveal scallops in the N400/word position function corresponding to these boundaries.

Our first reports of the word position effect examined normal semantically congruous sentences. Subsequent experiments were designed to verify that the N400 amplitude decrement was indeed due to sentence context and not to some other factor such as a neural refractory period for the N400, similar to that described for the auditory N1 (Davis, Mast, Yoshie, & Zerlin, 1966). We also wanted to differentiate the possible contributions of a sentence's semantic and structural (syntactic) aspects. Finally, the initial experiment examined only the ERPs elicited by open class or content words (nouns, verbs, adjectives, -ly adjectives), whereas the next experiment in the series also examined the influence of word position on closed class or function

Table 2. *Examples of the Congruent, Syntactic, and Random Sentences*[a]

Congruent	The tenants were evicted when they did not pay the last two months rent.
	Most new drugs are tested on white lab rats.
	She played the drums in a rock and roll band.
Syntactic	He ran the half white car even though he couldn't name the raise.
	In the wet levels fathers were smoking by congress.
	He prepared at the back hand to pair up his robbers.
Random	To prided the bury she room she of peanut the had china.
	She which had jazz anchor a she to straight couldn't gun.
	Be place prefer the was city it and sure be perfume.

[a]One hundred sentences of each type were used in Van Petten and Kutas (1991a).

words (articles, prepositions, pronouns, etc).[1] The initial word-position finding was extended by using sentence materials like those shown in Table 2 (Van Petten & Kutas, 1991a). The *congruous* sentences were like those used in previous experiments. The *syntactic* sentences were constructed by taking a different set of normal sentences and replacing each open class word with one of the same form class (e.g., nouns for nouns, adjectives for adjectives, etc.) to leave a legal but meaningless English sentence.[2] *Random* "sentences" were constructed by starting with another set of normal sentences, replacing the open class words, and rearranging word order to create illegal and meaningless word strings.

The electroencephalographic (EEG) data from this experiment were initially averaged into 1-s ERP epochs beginning 100 ms before the onset of each word, contingent on sentence type and the position of the word in its sentence. These averages suggested that the prestimulus baselines for the various conditions were not equivalent; some of the differences between

conditions appeared to begin at stimulus onset. Averages over a longer epoch with a pre-sentence baseline revealed that, in addition to the relatively short latency ERPs elicited by each word, there were slow potential differences between the three sentence types. In particular, Figure 3A shows that the random word strings were marked by a slow positive shift, which began at about the third word and increased in amplitude as the random strings progressed. Because the random strings were syntactically incoherent throughout, this slow positive potential may be similar to the recently reported "P600" response to occasional syntactic errors in otherwise normal sentences (Osterhout & Holcomb, 1992, 1993; Hagoort, Brown, & Groothusen, 1993). Because we were interested in evaluating the sensitivity of more phasic potentials to the experimental manipulations, we used a digital filter to separate higher-frequency components, such as the N400, from the slow positive potential. Figure 3B shows that N400 differences among the conditions could be observed after filtering out the slow potential.

For open class words, only the congruous condition yielded a decline in N400 amplitude as the sentences progressed; syntactic and random words elicited N400s of equivalent amplitude throughout the sentences (Van Petten & Kutas, 1991a). This result indicated that the word position effect is due to semantic aspects of sentence comprehension rather than some nonspecific effect of reading sequential words. We have observed the word position effect in every set of congruous sentences examined to date but have failed to find it in experiments in which subjects read connected text, as seen in Figure 4. We attribute this to the fact that readers do not start from scratch when processing sentences in coherent text but apply general discourse concepts derived from the preceding sentences and paragraphs. The absence of a word position effect in text suggests that the semantic factors driving N400 amplitude do not observe sentence boundaries but instead reflect the reader's conceptual representation of the material being read. This conclusion has been confirmed in a recent study by St. George, Mannes, and Hoffman (1994). The stimuli in their study consisted of deliberately vague paragraphs that are difficult to comprehend unless the reader is provided with an informative title beforehand, like those used by Bransford and Johnson (1972).[3] The amplitude of the N400 elicited by all the paragraph words was substantially smaller when subjects were allowed to read the informative title first.

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[1]Linguists have traditionally divided words into "major" and "minor" classes, but the division has been labeled in different ways, reflecting a variety of ideas as to exactly what the distinction is and where it should be drawn (see Caplan, 1987; Garnsey, 1985). The major class is usually held to consist of nouns, verbs, most adjectives, and the *-ly* adverbs. An inclusive definition of the minor class consists of some 500 words in English, including auxiliary verbs (*was*), articles (*the*), complementizers (*which*), conjunctions (*or*), other sentence connectors (*thus*), interrogatives (*who*), verb particles (*not*), prepositions (*of*), pronouns, and some adjectives and adverbs (*much, often, very*). One dichotomy is "open versus closed class," which stresses the idea that new nouns and verbs are added to a living language on an almost daily basis, whereas the closed class does not readily admit new members. For example, the past few decades have seen attempts to add a new gender-neutral pronoun to English, but our continued use of "he or she" bears witness to the "closed-ness" of the "closed class." A different dichotomy—"content versus function"—stresses the idea that content words carry most of the semantic information in a sentence, whereas the function of "function" words is to create syntactic structure. Both contrasts are intuitive, but neither allow a true dichotomy. The open/closed contrast is based on historical language change, which occurs continuously. The content/function contrast is also more of a continuum than a sharp boundary. Generic content words such as *do, go,* and *stuff* convey little more semantic information than function words such as *beneath, toward,* and *often*. Moreover, the syntactic properties of content words, such as whether or not a verb can take a direct object, also play a major role in creating syntactic structure.

[2]Transitive verbs were replaced with other transitive verbs, and intransitive with intransitive. In addition, only *-ly* adverbs were replaced; quantifiers such as *some* and *many* were not replaced in constructing the syntactic sentences. Our dichotomous assignment of words to the open or closed class followed a similar principle of assigning words of ambiguous class to the closed class category.

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[3]The stimuli in the study by St. George, Mannes, and Hoffman (1994) were full paragraphs, but analogous stimuli can consist of single sentences:"*parachute*; The haystack was important because the cloth had ripped."
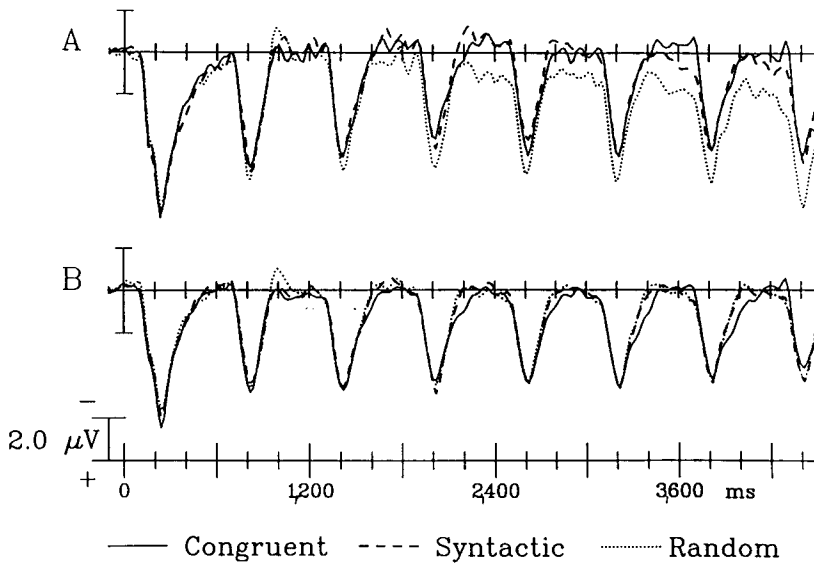
A

B

2.0 μV

+ 0   1,200   2,400   3,600 ms

——— Congruent   - - - - Syntactic   ·········· Random

Figure 3. (A) Grand average ERPs from C3 for the first seven words of each sentence type, unfiltered. (B) The same data after applying a digital hipass filter to the EEG before averaging (Van Petten & Kutas, 1991a).
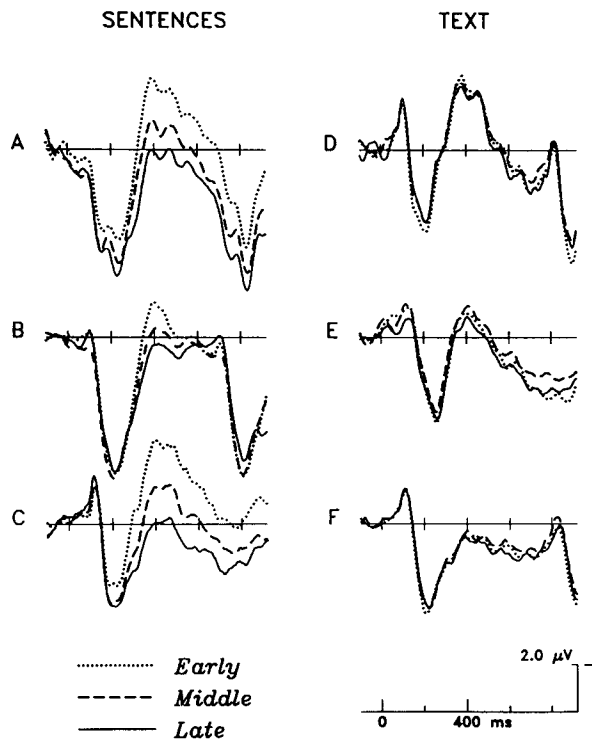
SENTENCES   TEXT

A   D

B   E

C   F

·········· *Early*   2.0 μV
- - - - - *Middle*
——— *Late*   0   400 ms

Figure 4. Grand average ERPs elicited by open class words according to position within congruous sentences, excluding initial and final words. Experiments A-C used isolated sentences; Experiments D-F used connected text. The numerical positions of *early, middle,* and *late* vary somewhat across experiments but correspond roughly to positions 2-3, 4-6, and 7+. Scalp site Cz. Data are from (A) Van Petten (1993), (B) Van Petten and Kutas (1991a), and (C) Van Petten and Kutas (1990). (D) Data are from unpublished observations from Kutas, Bates, Kluender, Van Petten, Clark, and Blesch (1988). The subjects were 15 adult monolingual English speakers reading children's stories in English. (E) Data are from unpublished observations from the experiment described in Van Petten, Kutas, Kluender, Mitchiner, and McIsaac (1991). The subjects were 16 adult monolingual English speakers reading nonfiction texts drawn from the *Reader's Digest.* (F) Data are from unpublished observations from Kutas et al. (1988). The subjects were 30 Spanish/English bilingual adults reading children's stories in Spanish.

Neither the syntactic nor random conditions yielded a word position effect for N400 amplitude. Moreover, the overall N400s elicited by open class words in these two conditions were indistinguishable, as seen in the left side of Figure 5. Given the dramatic subjective differences between the syntactic and random word strings, this latter finding may seem counterintuitive. But our hypothesis that N400 amplitude reflects the degree of contextual constraint would predict this result. At best, syntactic structure can indicate that the next open class word must be of a particular form class. This is a very weak constraint; knowing that an upcoming word should be a noun leaves a broad range of possibilities. In many cases, syntactic constraints on open class words are not even this strong; an article predicts a upcoming noun, but the noun might be preceded by one or more adjectives or adverbs. The weakness of syntactic as compared with semantic constraint is supported by the existing literature using behavioral measures (Tyler & Marslen-Wilson, 1986; Tyler & Wessels, 1983; Wright & Garrett, 1984). In contrast, syntactic constraints on closed class words might be stronger and more specific. For example, given the regularities of English, one might predict that *the* would follow *from*: prepositions are followed by noun phrases, most noun phrases begin with articles, and there are only a few articles in the English language (for comparisons of the predictability of open and closed class words, see Aborn, Rubenstein, & Sterling, 1959; Gough, 1983; Smith-Burke & Gingrich, 1979). Accordingly, we did observe N400 amplitude differences among the three sentence types for closed class words. The N400 elicited by closed class words is small overall, perhaps due to their high frequency of usage and predictability. But the right column of Figure 5 shows that a small amplitude negativity in the latency range of 300-400 ms was modulated by sentence context; the syntactic condition fell midway between the congruent and random conditions. This "closed class N400" had the same scalp distribution as that elicited by open class words; its shorter apparent duration is due to overlap with a later negative wave (the "N400-700") discussed below. However, the closed class N400 was not influenced by word position, suggesting that sentence constraints on closed class words operate locally rather than building up across the course of a sentence (for other reports of N400s elicited by closed
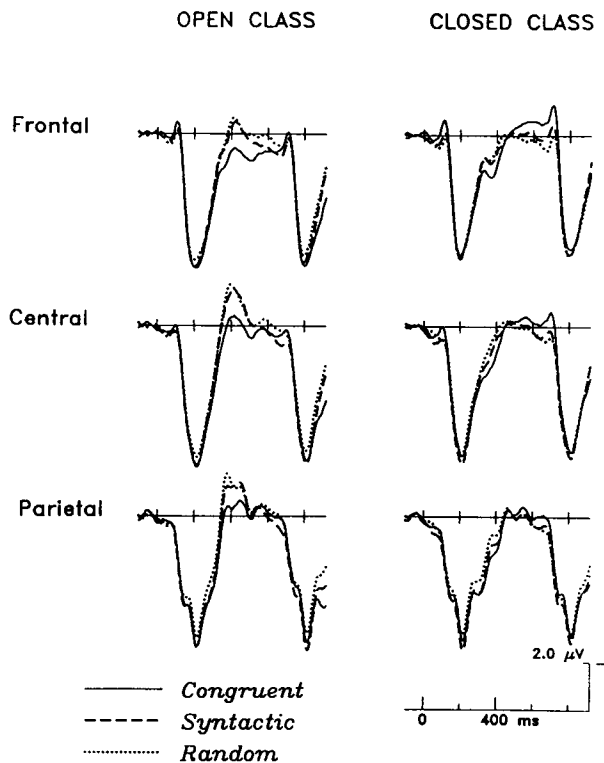
OPEN CLASS   CLOSED CLASS

Frontal

Central

Parietal

2.0 μV

—————— *Congruent*
- - - - - *Syntactic*
············· *Random*

0   400 ms

Figure 5. Grand average ERPs from Fz, Cz, and Pz recorded from 38 subjects (data from Van Petten & Kutas, 1991a). The amplitude and duration of the N400 difference is smaller than that observed in other experiments due to the application of a digital high-pass filter with a cut-off of 1 Hz. The text explains the motivation for applying this filter.

class words, see King & Kutas, in press; Kluender & Kutas, 1993b).

Differences between the ERPs elicited by open and closed class words have been reported in a number of studies (Kutas & Hillyard, 1983; Neville et al., 1992). Neville et al. described the differences as consisting of a larger N400 for open class words, a larger frontally distributed N280 for closed class words, and a slow frontally distributed negative wave dubbed the N400-700, which is also larger for closed than for open class words. Such ERP differences are potentially of great interest for two reasons. On the one hand, closed class words typically make different contributions to sentence structure than do open class words, such as introducing new sentence constituents. For instance, the word *that* in "The boy that the dog bit is feeling fine," introduces a relative clause. It is thus possible that one or more of the observed ERP differences reflect the utilization of the cues that closed class words offer for parsing a sentence. On the other hand, a variety of other processing distinctions have been attributed to the two vocabulary classes, some of which are independent of the differential roles they may play in sentences. Among these are that (a) production and comprehension of closed class words are more severely impaired in aphasia due to frontal lobe damage (Kean, 1985; Rosenberg, Zurif, Brownell, Garrett, & Bradley, 1985), (b) frequency of usage influences reaction time to open but not closed class words (Bradley, 1983), (c) divided visual field presentation produces different patterns of asymmetry for the two classes (Bradley & Garrett, 1983), (d) closed class words are less subject to speech errors (Garrett,

1982), and (e) closed class words are acquired later in childhood (Gleitman, Gleitman, Landau, & Wanner, 1989). However, some of these claims have been challenged on empirical grounds, and others have been attributed to factors that are correlated but not intrinsic to the open/closed distinction, such as the tendency for closed class words to be high in frequency of usage, short in length, and lacking in phonological stress (Bates & Wulfeck, 1989; Besner, 1988; Bock, 1989; Chiarello & Nuding, 1987; Dell, 1990; Gordon & Caramazza, 1985; Kean, 1979; Kolk & Blomert, 1985; Petocz & Oliphant, 1988; Shapiro & Jensen, 1986).

The observed ERP differences between open and closed class words in sentences may thus be related to (a) their differing syntactic roles, (b) intrinsic differences between the open and closed class vocabulary per se, and/or (c) other factors that are influential in processing both open and closed class words but that tend to be correlated with class membership. I have already suggested that the smaller N400 elicited by closed than open class words in sentences may be due to their higher frequency and greater predictability (see also Garnsey, 1985; Kluender & Kutas, 1993b). Recent work by King and Kutas (1995) has suggested that the N280 may be sensitive to word frequency and length rather than vocabulary class per se (but see Neville et al., 1992).

The contrast among congruent, syntactic, and random sentence types may shed some light on the functional significance of the N400-700 component. Figure 6A contrasts the ERPs elicited by open and closed class words in congruent sentences and illustrates the typical result of a larger N400-700 elicited by
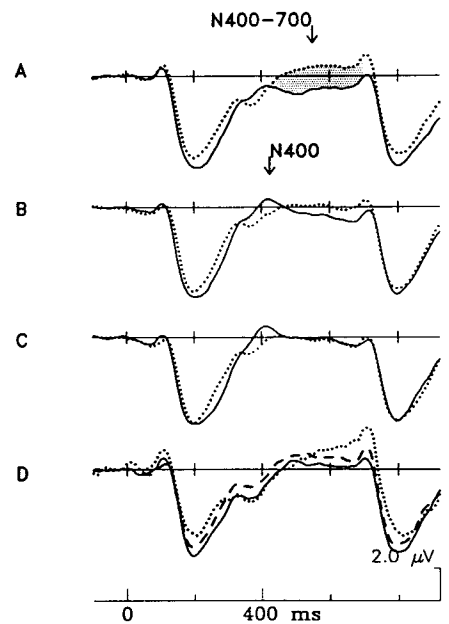
N400-700

A

N400

B

C

D

2.0 μV

0   400 ms

Figure 6. Intermediate sentence words. Rows A–C show the ERPs elicited by open (solid line) versus closed (dotted line) at Fz. In congruent sentences (A), these are distinguished by a slow late negative potential dubbed the N400-700. This potential is small in syntactically structured but semantically anomalous sentences (B) and absent in random word strings (C). Row D shows that the N400-700 develops over the course of congruent sentences: the solid line indicates closed class words occurring in the third and fourth sentence positions; the dashed line represents the fifth and sixth sentence positions; and the dotted line represents the ninth and tenth positions (data from Van Petten & Kutas, 1991a).

closed class words (this is also apparent in Figure 5). The N400–700 proved sensitive to overall sentence condition: Figure 6B shows that closed class words in syntactic sentences also elicited an N400–700, and Figure 6C shows that the same words in random sentences did not. These results indicate that the component is tied to some aspect of sentence processing rather than vocabulary class per se, but the larger amplitude in congruent than in syntactic sentences also suggests that the N400–700 is sensitive to more than purely syntactic factors. Finally, Figure 6D shows that the N400–700 develops over the course of congruous sentences, becoming larger with increasing word position. This pattern of results is consistent with the hypothesis that the N400–700 is a member of the contingent negative variation (CNV) family of potentials (Hillyard, 1973; McCallum & Papakostopoulos, 1973; Walter, Cooper, Aldridge, McCallum, & Winter, 1964) and that its amplitude reflects a subject's degree of anticipation while waiting for the next word to appear when sentences are presented in a word-by-word format. Closed class words are particularly likely to elicit anticipatory processes because they are fixated for short periods of time in natural reading, but our typical presentation format includes a uniform interval between words. Closed class words also tend to occur at the beginnings of phrases but signal that more informative open class words are coming (see King & Kutas, in press). The larger amplitude N400–700 in congruous sentences might thus be attributed to subjects' more active involvement in reading these as compared with meaningless word strings. These speculations about the identity of the N400–700 and CNVs elicited in nonlinguistic paradigms might be tested by varying the interval between successive words, and by comparing the scalp distributions of slow negative potentials elicited during sentences versus nonlinguistic strings of stimuli.

Figure 7. Grand average ERPs elicited by open class words at Cz in three sentence types. *Early* and *late* refer to approximately the first and second halves of the sentences, excluding the initial and final words. *High frequency* is defined as 30/million or higher when summed across all regularly inflected forms in the Francis and Kucera (1982) corpus; *low frequency* is 29/million or lower (Van Petten & Kutas, 1991a).

Sentence Context and Word Frequency

The experiments reviewed above indicate that the decline of N400 amplitude across a congruent sentence can be taken as an index of sentence-level semantic context. We have used this word position effect as a vehicle to examine the relationship between sentential context and lexical variables. One such lexical variable is *word frequency*. The normative frequency with which single words occur in the language is calculated by examining many samples of written or spoken discourse and scoring the number of occurrences of each word (see Francis & Kucera, 1982). As such, frequency is a purely lexical characteristic. In nearly all laboratory tasks using isolated words, subjects require longer exposure durations or more time to respond to rare than to common words (e.g., Rubinstein, Garfield, & Millikan, 1970; Solomon & Howes, 1951). The ubiquity of word frequency effects has led many theorists to give this factor a prominent place in models of word recognition (Becker, 1980; Bradley & Forster, 1987; Marslen-Wilson, 1987; Morton, 1969; Norris, 1986; Sharkey & Sharkey, 1992). The role of both frequency and semantic context has received different treatment across models, so that both additive and interactive effects of the two factors have been predicted (for reviews, see Van Petten & Kutas, 1990, 1991b). In several models, the underlying mechanisms for both frequency and context effects are closely tied to the demands of particular laboratory tasks such as pronunciation and lexical decision. Different information can be gleaned by examining dependent measures that can be collected without imposing a task in addition to language comprehension. Both eye move-
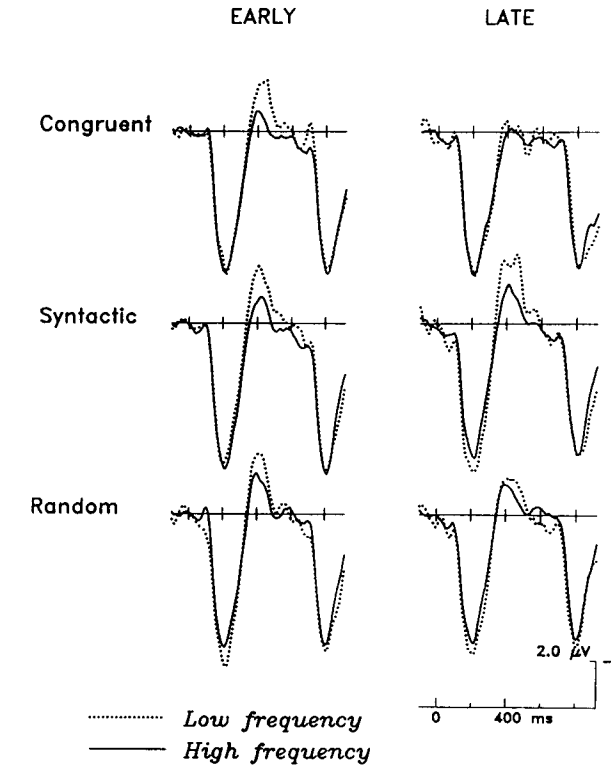
ments and ERPs are elicited spontaneously as subjects read so that these methods do not depend on the imposition of a secondary task.[4] Both of these unobtrusive measures show word frequency effects. Gaze durations are longer for low- than for high-frequency words (see Rayner & Sereno, 1994). In lists of single words, larger N400s are elicited by low-frequency words (Rugg, 1990; Smith & Halgren, 1987).

We have used ERPs to examine the relationship between word frequency and sentence context. In the study including congruent, syntactic, and random sentence types, low-frequency words occurring near the beginning of all three sentence types elicited larger N400s than high-frequency words, as seen in Figure 7 (Van Petten & Kutas, 1991a). As the sentences progressed, the N400 frequency effect in congruent sentences was eliminated, but in the conditions without semantic context, low-frequency words continued to elicit larger N400s. Similar interactions between the word position effect (a measure of sentential semantic context) and the lexical variable of word frequency have been observed in several other experiments (Van Petten & Kutas, 1990; Van Petten, unpublished observations). Figures 8 and 9 show

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[4]Of course, eye movements are detrimental to standard ERP recording procedures due to the associated electrooculographic artifacts. In all of the studies reviewed here, spontaneous eye movements were discouraged by presenting sentences one word at a time for brief durations, and trials contaminated by EOG artifacts were excluded from the averaged ERPs.
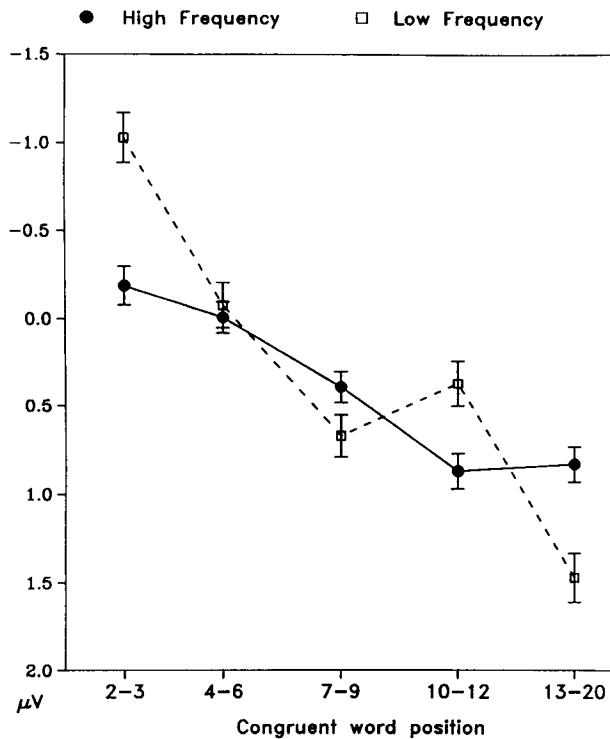
Figure 8. Mean voltage within the peak latency range of the N400 (300–500 ms poststimulus onset) for open class words in congruent sentences relative to a 100-ms prestimulus baseline. Examples of the sentences are shown in Table 3; the critical word pairs shown there were also excluded. The amplitude measure is averaged across all electrode sites (Van Petten, 1993).

that the word frequency effect is eliminated fairly early in meaningful sentences but persists throughout semantically anomalous sentences. Figure 8 also shows that the interaction between word position and frequency cannot be attributed to a "floor effect" in N400 amplitude. Although the word frequency effect was eliminated by about the fifth word of congruent sentences, N400 amplitude continued to decline with increasing word position. This pattern of results indicates that, although word frequency is a lexical variable, the human language-processing system does not always respect the boundary between lexical and sentential processing. These data thus conflict with hierarchical models of language processing that stipulate a purely "bottom-up" relationship between words and sentences. They do not, however, rule out the possibility that there may be several "word frequency effects," some of which are contingent on the use of particular behavioral tasks and are not reflected in N400 amplitude (see Balota & Chumbley, 1984, 1985; Van Petten 1991b).

Lexical Versus Sentential Semantic Context

Semantic context manipulations do not require sentence materials; reports of the impact of semantic context in pairs or lists of words number in the hundreds (see Balota, 1990; DeGroot, 1990). Shortly after Kutas and Hillyard (1980a) described the N400 in sentence contexts, other investigators reported similar N400 effects with word pairs or lists (Bentin, McCarthy, & Wood, 1985; Harbin, Marsh, & Harvey, 1984; Rugg, 1985). However, explaining how both single-word and sentence con-

texts can both yield "priming" effects has been a nagging problem in psycholinguistics. The most frequently cited explanation for lexical context effects is "spreading activation," a mechanism that allows the processing of one word to strengthen temporarily the long-term memory representation for another word due to structural links between associated items (Collins & Loftus, 1975). Whether or not spreading activation is a viable mechanism for lexical context effects, it clearly cannot account for sentential context effects. Because the number of congruent sentences is infinite in any natural language, there can be no preexisting links between every particular sentence and all the single words it may contain. Many investigators who have considered both varieties of context effect have opted for different underlying mechanisms. One view is that lexical context may exert at least some of its influence through a fast and automatic mechanism such as spreading activation within the mental lexicon, whereas sentential context acts via a slower, more strategic mechanism that is part of an entirely different "level" of the language-processing system (Fodor, 1983; Forster, 1981; Seidenberg et al., 1982; Till et al., 1988). This view is closely associated with those described in the lexical ambiguity section in proposing two discrete stages of semantic analysis, either of which can lead to differential processing (or priming) of subsequent words. One clear prediction from this model is that a sentence-level context effect should have a slower onset than a lexical-associative context effect.

A prediction about the time course of context effects is one well suited to a test by the ERP methodology. Sentences such as those shown in Table 3 were used to contrast the two vari-
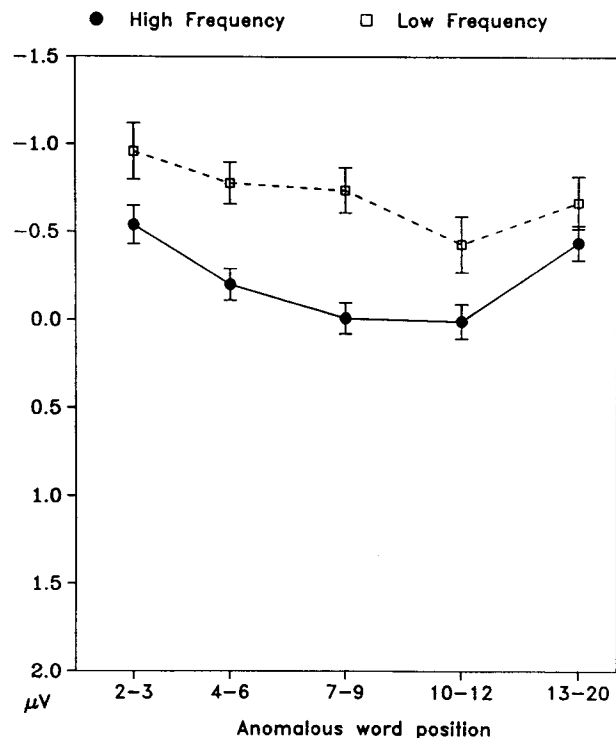

Figure 9. Mean voltage within the peak latency range of the N400 (300–500 ms poststimulus onset) for open class words in semantically anomalous sentences relative to a 100-ms prestimulus baseline. Examples of the sentences are shown in Table 3; the critical word pairs shown there were also excluded. The amplitude measure is averaged across all electrode sites (Van Petten, 1993).

Table 3. *Examples of the Stimuli Used to Compare Lexical and Sentence-Level Context[a]*

Congruent associated	When the *moon* is full it is hard to see many *stars* or the Milky Way.
	There were advantages to living in a *city* but Martha moved to a small *town* for the peace and quiet.
Congruent unassociated	When the *insurance* investigators found out that he'd been drinking they *refused* to pay the claim.
	The biologist went to the desert every *week* to collect a particular *species* of lizard that he hoped to study.
Anomalous associated	When the *moon* is rusted it is available to buy many *stars* or the Santa Ana.
	There was jewelry to drumming in a *city* but Martha turned to a gray *town* for the lizard and scones.
Anomalous unassociated	When the *insurance* supplies explained that he'd been complaining they *refused* to speak the keys.
	The shirt went to the gun every *week* to keep a good *species* of fumes that it hired to see.

[a]One hundred twenty sentences of each type were used in Van Petten (1993). Across conditions, the critical words (italicized) were matched for length, frequency, and position in the sentences. The experiment was conducted in two sessions so that subjects saw each critical word pair only once in each session.

eties of context (Van Petten, 1993). Each sentence contains a critical pair of words. In the *congruent-associated* condition, the two critical words are embedded in a meaningful sentence but are also related to each other independent of the sentence context. As compared with the first word of the pair, the second can thus benefit from a greater general sentence context and 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 can benefit only from the preceding lexical associate. In the *congruent-unassociated* condition, the critical words are only related via the general sentence context. The ERP elicited by the second critical word should differ from that of the first critical word only as a consequence of sentential context; the difference between the critical words in this condition is, in fact, a subset of the more general word position effect described earlier. Finally, the *anomalous-unassociated* condition is a control in which we expected no N400 amplitude difference between the first and second words of the critical pairs. Figure 10 shows that the results were as expected in that three of the four conditions resulted in a decrement of N400 amplitude from the first to second critical words. The latency data were, however, of greater interest for testing the hypothesis that the sentential context effect would be delayed relative to the lexical one. The onset latencies of the effects in the congruent-unassociated and anomalous-associated conditions were indistinguishable. Like the ambiguity study, these results provide no evidence for a strictly lexical stage of semantic analysis that precedes sentence integration.

The data did, however, reveal an interesting difference between lexical and sentential contexts. Essentially every subject showed an N400 amplitude difference between associated and unassociated word pairs, but there was substantial individual variability in the amplitude of the sentential context effect.[5] Post hoc analyses showed that the amplitude of a subject's sentential context effect was correlated with performance in the behavioral task assigned during this experiment (Van Petten, 1993). Although an overt behavioral task is not necessary to observe semantic context effects in the ERP, including one is use-

ful for encouraging subjects to stay alert and engaged in their primary task of reading for comprehension. The criteria I have used in selecting a task for sentence studies are that the task (a) not introduce decision-related P300s during the ERP epochs of greatest interest and (b) not draw attention away from comprehension of the sentences.[6] In this experiment, a single word appeared 1.5 s after each sentence, and subjects decided whether or not the word had been a part of the preceding sentence. Half of the probe words occurred in the preceding sentence and half

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[6]A number of studies have reported that the typical N400 effects are reduced when subjects attend to stimuli other than the eliciting ones (see Bentin, Kutas, & Hillyard, 1995; Gunter, Jackson, Kutas, Mulder, & Buijink, 1994; McCarthy & Nobre, 1993; Otten, Rugg, & Doyle, 1993).
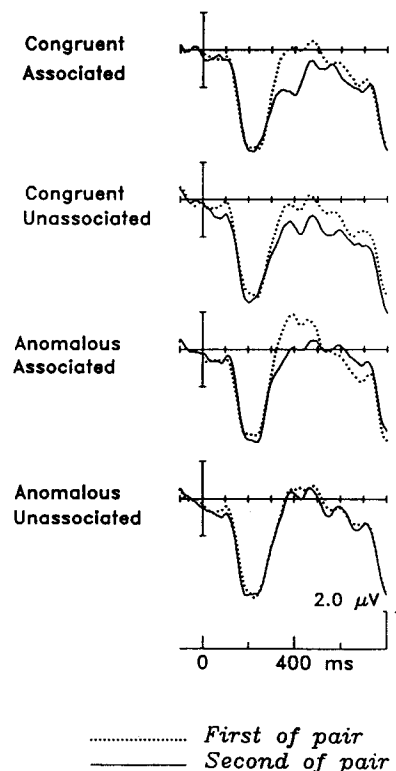

Congruent Associated

Congruent Unassociated

Anomalous Associated

Anomalous Unassociated

2.0 μV

0   400 ms

.... *First of pair*
———— *Second of pair*

Figure 10. Grand average ERPs from 28 subjects at scalp site Cz (Van Petten, 1993).

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[5]The sentential context effect was defined as a subset of the more general word position effect: a decline in N400 amplitude from the first to second member of the critical pairs in the congruent unassociated condition. The slope of the more general word position effect across all congruent sentences also varied among subjects; those with a large sentential context effect also had steeper slopes in the function relating word position and N400 amplitude.

did not; the words forming the critical pairs were never used as probe words. The amplitude of a subject's sentential context effect was correlated with his or her performance in this probe recognition task, particularly performance for closed class targets that had lower overall recognition levels ($R^2 = .40$). The top half of Figure 11 shows this correlation: the behavioral performance of each subject is plotted against the amplitude of the sentential context effect, where this is defined as the amplitude of the N400 elicited by the first word of the congruent-unassociated critical pairs minus the second word of these pairs. By contrast, the amplitude of the purely lexical context effect observed in the anomalous-associated condition was not related to performance in the probe recognition task, as shown in the bottom half of Figure 11.

Because the probe recognition task concerns only the immediately preceding sentence, it draws primarily on working memory. Many aspects of sentence comprehension — syntactic parsing, linking pronouns to their antecedents, and thematic role assignment — place clear demands on working memory. Other investigators have noted that working memory capacity is strongly correlated with language comprehension across a variety of tasks (for review, see Carpenter, Miyake, & Just, 1994). The relationship between the N400 measure of sentence comprehension and performance in a working memory task is thus a plausible one. In contrast, holding only a single related word in memory is sufficient to elicit a lexical context effect, and this is unlikely to place severe demands on working memory. In the study described here, working memory ability was defined by performance in the probe recognition task and linked with the sentential context effect in a post hoc analysis. In a follow-up study using the same sentence materials presented at a faster rate, we administered a more established measure of verbal working memory capacity before the experiment (the "reading span" test of Daneman and Carpenter, 1980). The subjects with low reading spans also performed more poorly on the probe recognition test than those with higher reading spans, suggesting that the two measures tap the same cognitive ability. The ERP results confirmed those of the first experiment in showing that the low-span readers lacked sentence-level context effects for intermediate words, although the amplitude of the lexical context effect was equivalent across reading span groups (Van Petten, Weckerly, McIsaac, & Kutas, in preparation).

The traditional model tested in the contrast between lexical and sentential context effects had two main tenets: (a) that sentence-level semantic analysis occurs only after analysis of the meanings of each individual word and (b) that each stage could exert an independent effect on the processing of subsequent words. The failure to observe a latency difference between the lexical and sentential context effects was inconsistent with the idea that the two sources of context are applied in serial order. The overall similarity between the lexical and sentential context effects suggests little difference in the timing or manner in which different sources of context are applied (see also Kutas, 1993). Instead, the differential relationship between measures of working memory capacity and the two context effects suggests that it may be more fruitful to think about how different sources of context are derived. Experimenters often define *context* as whatever stimuli are presented prior to a target item, but of course it is only the subject's mental representation of these stimuli that can influence his or her subsequent processing. The important difference between lexical and sentential contexts may be in the degree and nature of the effort required to compile the context
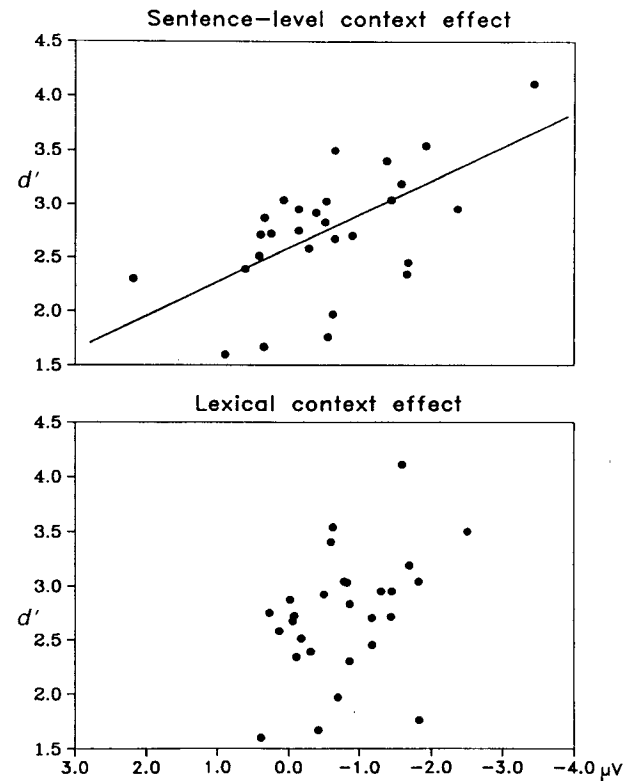

Figure 11. The top panel illustrates the relationship between behavioral performance in the working memory task embedded within the experiment. The y-axis represents performance summarized by d'. This measure combines accuracy for targets that occurred in the preceding sentence (correct response of "yes/present") and targets that did not occur in the preceding sentence (correct response of "no/absent"). The d' was calculated by considering correct responses to "present" probes as hits and incorrect responses to "absent" probes as false alarms. The x-axis represents the difference in the amplitude of the N400s elicited by the first and second members of the critical pairs in the congruent-unassociated condition (mean voltage 300–500 ms poststimulus onset, collapsed across all electrode sites). Negative amplitudes thus reflect larger context effects. Each data point represents one subject, and the regression line reflects the statistical relationship between performance and the ERP context effect. The bottom panel illustrates the lack of relationship between behavioral performance and our measure of the lexical context effect, the amplitude difference of the N400s elicited by the first and second members of anomalous-associated pairs. The regression analysis of the date in the bottom panel did not yield a significant correlation (data from Van Petten, 1993).

into a single concept, which can then facilitate the processing of upcoming words. The study of individuals supposed to have high or low working memory capacity is one avenue for quantifying the degree of effort involved in sentence comprehension. But because working memory is in danger of becoming a synonym for whatever computations and short-term storage are required to perform any task, controlled variation in stimulus materials is another avenue for understanding the nature and number of the processes involved in language comprehension. By analogy, single-unit physiologists working with nonhuman primates have dissociated cortical regions concerned with the short-term storage of spatial location versus object identity (Wilson, O'Scalaidhe, & Goldman-Rakic, 1993). It will be of some interest to determine whether or not all linguistic tasks and mate-

rials draw on a single pool of working memory resources; ERP researchers have just begun to approach this issue (see King & Kutas, in press; Kluender & Kutas, 1993a, 1993b). This review has focused on the N400, but the multicomponent structure of the ERP, together with newer functional imaging techniques, will aid in this endeavor.

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