Chapter

17

Tracking the Time Course of Meaning Activation

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The comprehension of text or speech requires of the reader/listener several conceptually distinct levels of analysis: recognition of individual letters or phonemes, recognition of the words so created, syntactic parsing of each sentence to determine the structural relationships between individual words, comprehension sentence meaning, and finally, an attempt to integrate individual sentences into a coherent message. For over a century psychologists have been interested in how these levels of analysis are combined to yield the rapid and seemingly effortless comprehension of language [James, 1890]. Some theorists have taken the human language processing system to be strictly hierarchical in that each processing component accepts input from only the immediately preceding lower level [Fodor, 1983; Forster, 1981; Garrett, 1978] while others have proposed more interactive models in which different facets of the system have more latitude to influence the computations and/or input to others [Marslen-Wilson and Tyler, 1980; McClelland and Elman, 1986].

A great deal of research has focused on word-level recognition (lexical) and its relationship to both lower (letter/phoneme detection) and higher (syntactic and semantic constraint) levels of analysis. It has been known for some time that a response to a given word can be speeded if it is preceded by a semantically related word. This apparent interaction between sensory and semantic analyses can, however, be accomodated within an autonomous framework of word recognition by the argument that such semantic priming effects reflect memory organization rather than on-line comprehension effects [cf Fodor, 1983; Seidenberg, 1982]. In this view, word recognition still proceeds in a strictly bottom-up fashion but, as a consequence of having "accessed" a given lexical entry, activation spreads to highly associated entries in the mental word store via a mechanism such as that proposed by Collins and Loftus [1975]. Semantic priming of this sort would seem to have little utility in the comprehension of a sentence or of extended discourse since it arises out of stable long-lived connections between lexical entries. Single words can acquire many different shades of meaning or connotations depending on their immediate context whereas it is unlikely that structural connections between entries in the lexicon could be so modified on a moment-to-moment basis.

The results of a number of recent experiments on lexical ambiguity have been seen as presenting a strong case for models which postulate autonomous lexical processing and which consider the integration of individual words into larger semantic units to be a subsequent and separate process.

1 *Lexical Ambiguity*

The fact that ambiguous words have a single physical representation but two or more semantic representations makes them a useful tool for examining the balance between data-driven (bottom-up) and concept-driven (top-down) processes in word recognition. [Norman and Bobrow,1975]. Three mutually exclusive possibilities exist for the cognitive processes engaged when a reader/listener encounters a lexical ambiguity. (1) Only the semantic representation appropriate to the prior context is activated (selective access). (2) The most common or dominant meaning of the ambiguity is accessed first with the subordinate meaning accessed only if the dominant meaning proves inconsistent with the context (ordered access). (3) Both meanings of the ambiguity are, at least briefly, activated (multiple access).

Evidence of selective access would imply that word recognition includes top-down processing by which sensory input is analyzed in light of the preceding context. Evidence of multiple access, in contrast, would suggest the presence of automatic, data-driven processing that acts independently of context and derives all possible meanings from the sensory input regardless of their relevance to the text. The ordered-access model also involves an automatic process that invariantly selects a meaning for a word regardless of context.

1.1 *A Partial Review of Previous Lexical Ambiguity Experiments*

The majority of studies of ambiguity resolution have supported the multiple access model (for a review see [Simpson, 1984]). Two primary experimental

measures have been used: reaction times (RTs) in a phoneme monitoring task, and RTs in priming paradigms with color naming, lexical decision, or word naming tasks.

The phoneme monitoring paradigm relies on the assumption that accessing multiple meanings of a word drains more cognitive resources than does accessing one meaning. Reaction times in the secondary task of phoneme monitoring are thus used as an index of the number of meanings that were accessed for a given word. Several investigators have presented auditory sentences and observed slower responses to target phonemes following ambiguous than unambiguous words [Foss,1970; Foss and Jenkins,1973; Cairns and Kamerman, 1975; Swinney and Hakes, 1976; Cairns and Hsu, 1980].

Recent reviews have emphasized difficulties in interpreting the results of lexical ambiguity studies which employed the phoneme monitoring task. Mehler, Segui and Carey [1978] noted that the comparison between ambiguous and unambiguous words was confounded by word length differences in some of the studies cited above. In addition, Newman and Dell [1978] pointed out that few of these studies controlled the degree of phonological similarity between the target phoneme and the initial phonemes of the ambiguous and unambiguous words. Simpson [1984] discussed these and other difficulties in the interpretation of phoneme monitoring studies.

Ambiguity studies using a priming paradigm have been less subject to methodological criticism and have, in addition, included a number of important variables such as the dominance of the sense of the lexical ambiguity used in the context, the strength of the context, and the temporal interval between words. A single trial in the priming studies to be discussed consisted of three stimuli: a semantic context biasing one sense of the ambiguity, the ambiguous word, and a target word which was related to one or the other meaning of the ambiguity or to neither.

Several investigators who have used a sentence fragment as the context have obtained evidence that targets related to both meanings of the ambiguity are primed relative to unrelated targets [Conrad, 1974; Onifer and Swinney, 1981; Oden and Spira, 1983; Seidenberg, Tanenhaus, Leiman and Bienkowski, 1982; Swinney, 1979]. Onifer and Swinney obtained this effect even when the sentence context biased the dominant meaning of the ambiguity and the target was related to the subordinate meaning, thus providing strong support for the multiple-access model versus either the selective- or ordered-access models. However, the results of Simpson [1981] are inconsistent with this conclusion in suggesting that dominance interacts with the strength of the sentence context. 'Strength of context' in Simpson's experiments was determined by having subjects rate the degree to which each sentence biased one of two possible interpretations of a sentence-terminal ambiguous word. With a weak biasing context, Simpson found that targets related to the dominant sense were always primed, whereas targets related to the subordinate sense were primed only if the sentence context biased this meaning. Given a stronger sentence context, only targets related to the contextually appropriate sense of the ambiguous words were primed, whether this was dominant or subordinate.

The importance of the 'strength of context' variable has also been examined in a series of experiments by Seidenberg et al. [1982] who contrasted sentences which were disambiguated only by syntactic or pragmatic information with sentences that also contained a semantic associate of the ambiguous word. It was found that neither syntactic nor pragmatic constraints (e.g., "He bought a rose" or "Go to the store and buy a spade") prevented multiple access. However, sentences containing semantic associates (e.g., "The bridge player trumped the spade") yielded evidence of selective access for ambiguities with two noun meanings, but not for ambiguities with a noun and a verb meaning. Based on these results, Seidenberg et al. argued that the influence of strength of context in determining lexical access can be reduced to a single factor, lexical priming or spreading-activation. These authors describe lexical priming as occurring *within* the same module that automatically derives candidate word meanings from the sensory input. According to this view, the finding of selective access under some circumstances does not necessarily implicate "top-down" context effects on lexical access. However, it is not clear how Seidenberg et al. [1982] determined that lexical priming alone was the important factor in producing selective access given that the various sentence types were not matched on other measures of contextual constraint such as cloze probability or a rating procedure like that used by Simpson [1981].

Existing data do not allow a clear statement as to the influence of strength of context on ambiguity resolution, in part because of the difficulty in comparing stimulus materials across different experiments. However, in its strongest form, the multiple access model holds that lexical access is context-independent. Thus, the more constraining the biasing context, the stronger will be the test of this model.

Another important factor in ambiguity resolution that can more easily be quantified is the temporal interval between the ambiguous word and its related targets. The multiple-access model holds that the two senses of an ambiguous word are only briefly activated until a slower process selects the contextually appropriate meaning. Studies which have manipulated the interval between the ambiguous and target words have shown that time is indeed an important variable [Kintsch and Mross, 1985; Onifer and Swinney, 1981; Seidenberg et al., 1982]. In general, a very short interval between the ambiguous word and the onset of the target word yields priming for targets related to both senses, whereas a longer interval yields priming for only targets related to the contextually appropriate sense.

In the experiments of Seidenberg et al. [1982], evidence of multiple access was obtained with zero delay between the offset of the ambiguity and the onset of the target word, but selective access was obtained with a delay of only 200

msec. These results suggest that, although it is slower than the presumably automatic process which derives all of the possible meanings from a single letter string, the selection process is still completed very rapidly. It is thus possible that Simpson's [1981] finding of selective access with strong context was due to the 120 msec delay between ambiguity and target.

The majority of ambiguity studies, then, are consistent with the idea that that all meanings of ambiguous words are simultaneously activated upon presentation, with the contextually irrelevant meaning being discarded at some later time. However, such conclusions do not strictly follow from the data.

2 An Alternative Interpretation of the Lexical Ambiguity Results

There is ample theoretical support for the idea that the human language processing system may utilize overlapping, cascaded or parallel processes to analyze more than one word at a time [Marslen-Wilson and Tyler, 1980; McClelland and Elman, 1986]. Empirical evidence also supports this concept; readers often do not fixate short function words in text but may gather information about these while fixating adjacent words [Rayner, 1983]. An overlap in the processing of individual words may be greatly encouraged if the words are related or similar along some dimension. When simultaneously presented with two words which are unrelated in meaning but share common letters, subjects may experience letter migration between the words and for instance, report having seen "lane" and "lice" rather than "line" and "lace" [Mozer, 1983]. Sanocki and colleagues [1985] have recently shown that the time required to find a nonword letter string embedded within a sentence is not only reduced by the presence of syntactic and semantic structure, but that the advantage of well-structured sentences over scrambled ones increased with the position of the target within the sentence. These results suggest that words in sentences are processed progressively faster as the syntactic and semantic constraints of the sentence develop. Marslen-Wilson and Tyler [1980] have reported similar findings in spoken word recognition.

The semantic priming literature also suggests that related words may be processed in an overlapping manner. There have been several demonstrations that lexical decisions are faster for pairs of simultaneously presented words if they are related than if they are not [Carroll and Kirsner, 1982; Fischler, 1977a; 1977b; Meyer and Schvaneveldt, 1971]. Moreover, Kiger and Glass [1983] have demonstrated that the *subsequent* presentation of a related word can result in faster lexical decision for a target word if the temporal interval between the two words is short.

The possibility that two words can be processed in an overlapping, cascaded manner has clear implications for the interpretation of lexical ambiguity results. Although all of the experiments to date have presented words in a serial manner, the experimental paradigm may be tapping into a system which is designed to begin analyzing a new word before the processing of the previous word is complete. It is thus possible that the finding of multiple access may be an artifact of the experimental paradigm designed to measure it. The target word, rather than serving as a neutral probe to determine how the preceding ambiguous word was processed, may itself serve as a source of context in the interpretation of the ambiguity. Although the sentence context may initially constrain access to a single meaning of the ambiguous word, the subsequent presentation of a word related to the alternate meaning could serve to activate this previously irrelevant meaning via a "backward priming" mechanism. The newly activated, irrelevant sense of the ambiguity would then be processed concurrently with its related target, leading to a shorter reaction time for this target.

The alternative interpretation of lexical ambiguity results offered above may prove experimentally difficult to distinguish from the multiple access model of ambiguity resolution. The critical issues in resolving the question are those of time.

One question is whether the SOAs (stimulus onset asynchrony) which produce multiple access are also those which lead to backward priming. Kiger and Glass [1983] observed backward priming in a word-pair lexical decision task at SOAs of less than 130 msec, while Seidenberg et al. [1982] observed multiple access in a sentence paradigm at delays of less than 200 msec. Allowing for the additional complexity of processing a sentence context over a single word context, these values are rather close to one another.

A second empirical question is whether backward priming acts quickly enough to influence the behavioral response being measured. Seidenberg and colleagues have argued that, unlike the lexical decision task, the naming task is not susceptible to backward priming effects [Seidenberg, Waters, Sanders, and Langer, 1984]. However, it is not clear that the "backward priming" discussed by Seidenberg et al. [1984; see also Koriat, 1981] is the same phenomenon as that observed by Kiger and Glass. Seidenberg measured both naming and lexical decision times for the second words of asymmetrically related word pairs, such as "stick-lip," which were highly related only in the "backward" direction. The SOA between the first and second word of a pair was 500 msec. So although the semantic relations between primes and targets were "backward," the temporal relations were "forward," in that the prime preceded the target. Given the relatively long SOA, it seems unlikely that prime and target recognition would have overlapped in time. The finding that naming latencies are unaffected by semantically backward priming may, then, have little or no bearing on the question of whether naming latencies may be affected by temporally backward priming.

In the sense that we will use the term, "backward priming" refers to temporal overlap in the processing of two words, and can be thought of as "mutual priming" analogous to that which occurs between two simultaneously presented words.

The experiment described below was designed to provide evidence about the time course of meaning activation via the recording of event-related brain potentials (ERPs). Before proceeding to the experimental details, a description of the technique and its relevance to the problem are in order.

3 Event-Related Potentials

Electrodes placed on the scalp can be used to record voltage fluctuations known as the electroencephalogram (EEG). It is generally believed that the electrical activity seen at the scalp is the summation of graded post-synaptic potentials (PSPs) generated by the depolarization and hyperpolarization of brain cells. (See [Wood and Allison, 1981] for a review of the neurophysiological basis of the EEG or [Nunez, 1981] for a treatise on the physics of EEG). At any given moment, the observed EEG is likely to reflect the activity of a number of functionally distinct neuronal populations. With the advent of computer averaging some two decades ago, it became possible to obtain an estimate of activity which is time-locked to some arbitrary point, such as the presentation of a stimulus. Averaging many epochs of EEG following the repetition of similar stimuli tends to result in the cancellation of the random background EEG, leaving a record of the evoked or event-related potentials (EPs or ERPs) which were synchronized to the stimulus presentation. The resulting waveform of voltage plotted against post-stimulus time typically contains a series of positive and negative peaks. Much ERP research has focused on the decomposition of these voltage fluctuations into experimentally dissociable "components" which can be linked to a given physiological and/or cognitive process. Attempts to identify a functionally distinct component may include manipulations of the physical (size, luminance, pitch, etc.) or psychological (task-relevance, meaningfulness, predictability, etc.) attributes of the stimuli, or the physiological state of the subject (drug administration, selecting a population with a particular type of brain damage, etc.). Polarity, latency, distribution across the scalp, and general waveshape are also factors in identifying a given component.

This sort of experimental logic has resulted in a heuristic division of ERP components into "exogenous" and "endogenous." (See [Donchin, Ritter, and McCallum, 1978; Hillyard and Kutas, 1983; Hillyard and Woods, 1979] for reviews.) Exogenous components are those which are mandatorily elicited by a given stimulus in a normal subject, regardless of the stimulus' "psychological" attributes. These are often referred to as the "early" (typically less than 200 msec post-stimulus onset) or "sensory" components of the ERP, in that they are tied to a particular stimulus modality, and their amplitude and latency are influenced by the intensity of the eliciting stimulus. Endogenous, "late," or "cognitive" ERP components are those which are not mandatorily elicited by a given physical stimulus but rather vary in amplitude and/or latency with the psychological attributes of the eliciting stimulus.

The identification of a given component as "cognitive" requires some care in that one must ensure that it is not due to some overlooked physical attribute of the stimuli. It is also desirable to attach some specificity to a given component, in that it can then be linked to some inferred cognitive process. Cognitive ERP researchers are currently engaged in this enterprise through the use of strategies similar to those used by other experimental psychologists to isolate inferred cognitive operations.

ERP components, exogenous and endogenous, are usually named by their polarity and peak latency (e.g., P100—a positivity peaking at 100 msec). For ease of comparison across experiments and conditions, however, this nomenclature has sometimes become frozen. For example, if a positive peak with the same scalp distribution occurs at 90 msec in response to bright flashes of light and a similar peak occurs at 108 msec in response to dim flashes, the experimenter might refer to both as a "P100" or simply a "P1." This discrepancy between nominal and observed latency is particularly apparent in the cognitive ERP literature where the observed latency of a component may vary widely with the timing of the underlying cognitive operation (see [Coles et al., in press; Kutas, McCarthy, and Donchin, 1977]). The peak latency of a positivity with maximum amplitude over central and parietal scalp may vary as much as three hundred msec depending on the difficulty of stimulus evaluation and the attendant reaction time, but it is generally referred to as a "P300" because the original experimental report of this component recorded a peak latency of 300 msec [Sutton et al., 1965].

3.1 *Event-Related Potentials and Semantic Priming*

Over the last few years a number of experimenters have recorded ERPs in semantic priming paradigms. In the experiments of Kutas and Hillyard, for example, simple sentences were presented one word at a time on a CRT screen. The final words of these sentences could either be sensible and predictable (as in "He mailed the letter without a *stamp*.") or nonsensical and unpredictable (as in "I take my coffee with cream and *dog*."). It was seen that the difference between sensible and nonsensical words consisted of a large negative wave beginning around 200 msec and peaking at 400 msec after the onset of the word. Thus the name "N400." Control experiments established that this response was specific to the meaningfulness (or lack thereof) of the terminal word, and was not a general "surprise" reaction. The presentation of a sensible word in a larger typeface, or a novel meaningless slide in the place of the final

word did not elicit N400s but rather P300s, while the presentation of a nonsensical word in a larger typeface elicited both an N400 and a P300 [Kutas and Hillyard, 1980a, 1980b, 1980c, 1984]. The relative independence of the N400 response from the physical characteristics of the eliciting word was confirmed by experiments demonstrating that N400-like difference waves could be elicited by speech and American Sign Language [Holcomb, 1985; Kutas, Neville, and Holcomb, in press; McCallum, Farmer, and Pocock, 1984; Neville, 1985].

The sentence experiments described above incorporated rather crude psycholinguistic manipulations in that the sentence-terminal words were either quite predictable or wholly anomalous. Other work has shown that the amplitude of the N400 is quite sensitive to finer gradations of semantic priming and expectancy. One experiment used interpretable congruent sentences which varied in the degree to which the preceding sentence fragment constrained the final word. For example, the sentence fragment "The bill was due at the end of the ..." is of high contextual constraint in that most people will choose "month" as the appropriate final word, while the fragment "He was soothed by the gentle ..." is of low contextual constraint in that there are many equally acceptable endings [Bloom and Fischler, 1980]. Such fragments were terminated by words of varying cloze probability,[1] a measure of how predictable or expected a given word is in a given context [Taylor, 1953]. In the examples given, both fragments could be terminated by words of equal (low) cloze probability as in "The bill was due at the end of the *hour*." and "He was soothed by the gentle *wind*.". The results of this experiment showed that the amplitude of the N400 elicited by the terminal word was highly correlated with its cloze probability and generally independent of the contextual constraint of the preceding sentence fragment, indicating that the N400 response does not require semantic anomalies or extreme violations of semantic expectancies [Kutas and Hillyard, 1984; Kutas, Lindamood, and Hillyard, 1984]. These results parallel those obtained with the lexical decision task [Fischler and Bloom, 1979], in that words of low cloze probability elicit large N400s and prolonged lexical decision times.

A number of experiments have demonstrated that the relationship between the N400 and semantic variables is not restricted to sentence paradigms. In tasks requiring a speeded lexical decision, a relatedness judgement, or a delayed letter search (such as that used in the current ambiguity experiment),

1 In a cloze probability procedure, a large group of subjects is asked to fill in the missing terminal word of a sentence. A word's cloze probability is defined as the proportion of subjects using that word to complete the sentence. The measurement of cloze probability for a particular word is dependent on the contextual constraint of the sentence. For a highly constrained sentence such as "He mailed the letter without a ________", the word "stamp" might have a high cloze probability, while "address" would have a low cloze probability. In contrast, a low constraint sentence such as "There was nothing wrong with the ________" might have a number of equally acceptable endings, none of which would have an extremely high cloze probability.

larger N400s are elicited by the second word of unrelated pairs than related pairs [Bentin, McCarthy and Wood, 1985; Harbin, Marsh and Harvey, 1984, Kutas, 1985; Kutas and Van Petten, in press; Rugg, 1985].

A subtle variant of word-to-word priming effects was also observed in the Kutas and Hillyard sentence paradigms. Namely, anomalous sentence completions which were related to the predictable sensible ending elicited smaller N400s than did unrelated anomalous endings, i.e., words such as "umbrella" in the sentence "The game was called when it started to *umbrella*." elicited smaller N400s than words such as "dog" in "I take my coffee with cream and *dog*." [Kutas, Hillyard, and Lindamood, 1984]. These results indicate that the amplitude of the N400 reflects lexical associations even when one of the words is not physically present, but only suggested by a preceding context.

A similar indication that the N400 is sensitive to lexical priming even within the context of a sentence comes from the work of Fischler and his colleagues [Fischler, Bloom, Childers, Roucos, and Perry, 1983; Fischler, Childers, Achariyapaopan, and Perry, 1985; Fischler, Bloom, Childers, Arroyo, and Perry, 1984]. In an experiment using simple categorical statements which could be true or false and affirmative or negative (four combinations), these authors found that the amplitude of the N400 elicited by the final word of such sentences depended on the relationship between the subject and the object rather than the truth value of the sentence. Statements such as "A robin is a *bird*." and "A robin is not a *bird*." both yielded smaller N400s than statements such as "A robin is (is not) a *vehicle*." regardless of the overall truth or falsity of the statements.

More recent data collected by our laboratory in sentence paradigms has served to strengthen our supposition that the N400 is closely linked to some aspect of word processing which is influenced by semantic factors. First, it has become apparent that open-class or "content" words (nouns, verbs, adjectives, etc.) elicit larger N400s than do closed-class or "function words" (articles, conjunctions, prepositions, etc.) ([Kutas, Van Petten, and Besson, in press; see also Garnsey, 1985] for content/function ERPs in a single-word paradigm). Second, we have noted that the amplitude of the N400 elicited by content words is not invariant over the course of a sentence. We supposed that, given a series of isolated sentences (as opposed to connected text), the first content word in each sentence would, by definition, be semantically unprimed and that later content words, on the average, would have accrued some degree of semantic priming over the course of the sentence. It was found that, in fact, N400 amplitude for intermediate sentence words did vary with word position, in that the first content word yielded a larger negativity than did later content words [Kutas, Van Petten, and Besson, in press]. A more fine-grained analysis of N400 amplitude by word position is ongoing.

This brief and partial review of existing evidence suggests that a particular component of the event-related potential, the N400, can be used as an empirical measure of the process known as "semantic priming," much as reaction time to press a button or say a word is used. The N400 or a similar negative component in the same latency range has also been shown to be sensitive to phonological priming, at least in tasks such as rhyme-detection where subjects are encouraged to make use of words' phonological aspects [Rugg, 1984a, 1984b], and perhaps to orthographic priming as well [Kramer and Donchin, 1987].

Most empirical measures of inferred underlying cognitive processes such as "lexical access" or "semantic priming" bring with them some unwanted baggage and some technical difficulties. In the case of some commonly used psycholinguistic tasks, experimenters are well aware of the drawbacks of particular tasks, but continue to apply them because of their demonstrated utility (see [Balota and Chumbley, 1984, 1985] for discussions of the lexical decision and naming latency tasks). The event-related potential measure is no exception to this general rule. One experimental constraint in the recording of ERPs is a limit on concurrent motor activity that the subject can be allowed to engage in. Eye movements, activity of facial muscles, and tongue movements each produce electrical artifacts which may obscure the record of ongoing EEG [Grozinger et al., 1980; Stuss et al., 1983]. In fact, our laboratory has found it useful to try to circumscribe concurrent *cognitive* activity in order to avoid eliciting multiple endogenous ERP components which occur in the same latency range. For instance, a well-studied large positive ERP component named the P300 generally appears in any task in which the subject is required to make a binary decision, as in go/no-go tasks or cases where the subject must press one of two buttons (see [Donchin, 1981; Johnson, in press; Kutas and Van Petten, in press; Pritchard, 1981]). Thus, semantic priming paradigms which require an on-line decision of this type typically result in the elicitation of an overlapping P300 and N400 within the same latency window. While not insurmountable, we feel that the difficulties involved in disentangling these two components can be avoided by eliminating the necessity for a task-related decision within the post-stimulus epoch of interest. It is quite possible to record priming-related ERPs with no overt behavioral responses required of the subject. In the series of Kutas and Hillyard sentence experiments described above [1980a, 1980b, 1980c, 1983, 1984], the subjects were simply instructed to read for comprehension in order to answer questions about sentence content at the end of the experiment. We consider the possibility of obtaining data related to language processing without requiring additional task-related cognitive operations to be one of the advantages of the ERP technique.

3.2 *Application of ERPs to the Problem of Lexical Ambiguity Resolution*

A second opportunity/advantage offered by ERP recordings is the possibility of obtaining a dependent measure which is temporally continuous over whatever pre- and post-stimulus epoch the experimenter chooses to measure. This stands in contrast to the typical behavioral response which occurs at some discrete instant in time. It was this opportunity which we exploited in the present study.

Two experiments are reported. The first is similar to previous ambiguity studies in using naming latency as the dependent measure. The primary purpose of Experiment 1 was to to insure that the stimulus materials constructed for this study would produce the expected priming effects for both contextually appropriate and inappropriate semantic associates of ambiguous words relative to unrelated target words. In Experiment 2, ERPs were recorded to these same stimuli.

4 *Experiment 1*

4.1 *Methods*

4.1.1 *Stimulus Construction* One hundred and twenty words with two distinct and unrelated meanings were selected. Half of these homographs had both a noun sense and a verb sense, the other half had two noun meanings. Published norms were used to select the subordinate sense of the homographs [Geis and Winograd, 1974; Gorfein, Viviani and Leddo, 1982; Kausler and Kollasch, 1970; Nelson, McEnvoy, Walling, and Wheeler, 1980; Perfetti, Lindsey and Garson, 1971]. No published data could be found for 18 of the 120 homographs used; in these cases the authors chose what seemed to be the less common sense of the word.

Each homograph was used in its subordinate sense to complete a sentence fragment. Biasing the sentence contexts toward the less common meanings of the homographs ensured that the 'contextually appropriate' target words would be related to this subordinate sense, whereas 'contextually inappropriate' targets would be related to the more dominant meaning. This design thus allows a distinction between the selective access model on the one hand and the multiple and ordered access models on the other hand, without being able to distinguish between the predictions of the latter two models. Any priming of the contextually inappropriate targets could arise either from exhaustive access of all of the homographs' potential meanings, or from a tendency to access the dominant meaning regardless of context.

An attempt was made to construct moderate to highly constraining sentence fragments for which the ambiguous words were the most likely completions. The success of this attempt was assessed by asking a separate group of 20 subjects to complete each sentence fragment with a single word. Each sentence was completed with the appropriate homograph by an average of 11 out of these 20 subjects. Representative sentences are shown in Table 1.

Three target words were selected to follow each homographic sentence: one related to the sense of the homograph used in its sentence ('contextually appropriate'), one related to the other sense of the word ('contextually inappropriate') and one which was unrelated to either sense ('unrelated'). There were no significant differences among the three target types in frequency of usage [Kucera and Francis, 1967]: contextually appropriate targets, 99 + 157 (mean + standard deviation); contextually inappropriate targets, 108 + 148; unrelated targets, 109 + 141; $F(2,359) = 0.18$, N.S.) No attempt was made to match the initial phonemes of the different classes of target words. A list of the homographs and targets used appears in Appendix 1.

Table 1 Sample stimuli for Experiments 1 and 2

Homograph sentence	Contextually appropriate target	Contextually inappropriate target	Unrelated target
The gambler pulled an ace from the bottom of the deck.	cards	ship	parent
It is not legal for an employer to consider a person's religion or race.	color	run	art
The logger cut down the tree with a chain saw.	ax	look	proof
The bicycle mechanic fixed the flat tire and repaired the broken spoke.	wheel	talked	pill
Filler sentence	**Related target**	**Unrelated target**	
He bought a quart of milk and a dozen eggs.	bacon	buckle	
The sweater was knitted from blue and grey wool.	lamb	cigar	

An additional one hundred and twenty sentences were completed with unambiguous words ('filler sentences'). Related and unrelated target words were chosen for each filler sentence.

Three separate stimulus lists were constructed. In each list, 40 of the homographic sentences were followed by a contextually appropriate target, 40 by a contextually inappropriate target, and 40 by an unrelated target. The type of target was counterbalanced so that, across lists, each homographic sentence was followed by each type of target. Half of the filler sentences in each list were followed by related targets, half by unrelated. Within each subject group, one-third of the subjects saw each list.

4.1.2 *Stimulus Presentation* Words were displayed in the form of brightened dot matrices on a CRT controlled by an Apple II microcomputer. The duration of each word was 200 msec. Each sentence was presented one word at a time with an SOA (the time from the onset of one word to onset of next) of 900 msec. Each sentence ended with a period such that subjects were aware of sentence terminations. Target words appeared at a location which was slightly below that of the sentence words to further differentiate target words from sentence words. For half of the subjects, target words appeared 16 msec after the offset of sentence terminal words to yield a total stimulus onset asynchrony (SOA) of 216 msec. For the other half of the subjects, sentence-target SOA was 700 msec.

Our 216 msec SOA condition is probably quite similar to the zero delay condition of previous ambiguity experiments which used cross-modal presentation [Onifer and Swinney, 1981; Seidenberg et al., 1982; Swinney, 1979]. The effective SOA in these experiments would have been equal to the duration of the auditorily presented ambiguity. Given a normal rate of speech, the SOA between ambiguity and target might then have been 200–300 msec.

4.1.3 *Subjects* Forty-two young adults, (age range 18–25 years, 22 male, 20 female) were paid for participating in the experiment. All had normal or corrected-to-normal vision.

4.1.4 *Procedure* Subjects were tested one at a time in a sound-attenuating chamber. They were instructed to read each sentence in order to complete a multiple-choice questionnaire about its contents at the end of the experiment, and to say each target word aloud as fast as possible. Each subject was given a practice run consisting of ten unambiguous sentences, five with related, and five with unrelated targets.

Assignment to SOA group and stimulus list was pseudorandom, with the constraint that 21 subjects were in each SOA group, and 7 subjects within each SOA saw a given stimulus list.

Table 2 Naming latencies in Experiment 1. SOA = stimulus onset asynchrony. Mean and standard deviation in msec. N=21 for both SOAs.

Target type	200 SOA	700 SOA
Filler related	602 (70)	542 (64)
Filler unrelated	627 (85)	569 (78)
Contextually appropriate	591 (73)	547 (71)
Contextually inappropriate	617 (77)	562 (69)
Homograph unrelated	635 (85)	571 (71)

Voice onset was recorded via a microphone and a voice-activated trigger. Together with stimulus codes, the responses were recorded by a PDP 11/34 computer.

4.1.5 *Data Analysis* Incorrect responses and responses that failed to trigger the microphone were excluded from analysis, as were reaction times shorter than 400 msec or longer than 900 msec. Approximately 3.2% of the trials were lost due to these reasons.

4.2 *Results*

4.2.1 *Filler Targets* The means of each subject were subjected to a 2 × 2 analysis of variance (ANOVA) with repeated measures, using SOA as a between-subjects variable and target type as a within-subjects variable. As seen by the mean naming latencies shown in Table 2, the long SOA group responded more quickly than the short SOA group for both target types, $F(1,40) = 6.69$, $p < .02$. Responses to related targets were faster than to unrelated targets, $F(1,40) = 61.0$, $p < .001$. There was no significant interaction between SOA and target type, $F(2,80) = 0.05$, N.S.

4.2.2 *Homograph Targets* The means of each subject were subjected to an initial 2 times 3 ANOVA with SOA and target type as factors. As for the filler data, there were significant main effects of SOA, $F(1,40) = 5.62$, $p < .05$ and target type, $F(2,80) = 59.6$, $p < .001$. There was also a significant interaction of SOA by target type, $F(2,80) = 5.22$, $p < .01$. A more detailed analysis of the interaction was carried out using the Dunnett test for comparisons with the control (unrelated) condition [Keppel, 1982]. Responses to contextually appropriate targets were faster than to unrelated targets at both SOAs: long SOA, $F(1,20) = 21.0$, $p < .01$; short SOA, $F(1,20) = 65.6$, $p < .01$. Responses to the contextually inappropriate targets were faster than unrelated targets at the short

SOA but not at the long SOA: long SOA, $F(1,20) = 5.58, p < .05$; short SOA, $F(1,20) = 21.2$, $p < .01$. A *posthoc* comparison (Tukey test, [Keppel, 1973]) showed that, although faster than unrelated responses, contextually inappropriate responses were slower than contextual responses at the short SOA, $F(1,20) = 48.9$, $p < .01$.

4.3 *Discussion*

Our results replicate those of previous studies in showing that, despite a sentential context biasing one reading of an ambiguous word, targets related to both senses are primed if the temporal interval between the ambiguous prime and its target is short [Kintsch and Mross, 1985; Onifer and Swinney, 1981; Seidenberg, Tanenhaus, Leiman, and Bienkowski, 1982]. Note that, in the present study, the contextually inappropriate targets were related to the dominant, higher-frequency sense of the homographs used. The RT facilitation observed for these targets is thus consistent with either the "multiple access" or "ordered access" model of ambiguity resolution.

Although faster than the RTs to unrelated targets, the contextually inappropriate target RTs were slower than those to contextually appropriate targets. This effect has been reported in past studies [Onifer and Swinney, 1981; Simpson, 1981], although it has not always been statistically significant ([Seidenberg et al., 1982; Swinney, 1979]; see [Simpson, 1984]). A greater degree of priming for contextually appropriate targets over contextually inappropriate targets may reflect preferential processing of the biased meaning of ambiguous words. Alternatively, it may reflect direct priming of the contextually appropriate targets by the sentence contexts independent of the ambiguous words.

In the present study, many (76 out of 120) of the homograph sentence contexts contained words which were lexically associated with the contextually appropriate targets (e.g., "The gambler pulled an *ace* from the bottom of the *deck. cards*"). The RTs to the contextually appropriate probes may then have reflected priming by intermediate words in the sentence as well as by the terminal homographs, a benefit not enjoyed by the contextually inappropriate targets. However, these lexically associated intermediate words occurred, on the average, 5.7 words (or 5.2 seconds) prior to the target words. We do not know if a lexical priming mechanism, when extended over so many words, could account for the differential priming of contextually appropriate and contextually inappropriate targets. It has been reported that semantic priming drops off sharply with even a single intervening item in word lists [Dannenbring and Briand, 1982; Foss, 1982], but can be maintained over intervening material in prose passages [Foss, 1982]. The present case falls somewhere between a word list and a passage, and the question of priming between sentence intermediate words and targets remains open. This issue will be examined at greater length in Experiment 2.

The primary purpose of Experiment 1 was to validate this set of sentences and targets for producing reaction time priming of both contextually appropriate and inappropriate targets of homographs. This purpose achieved, we proceeded to record ERPs to the same set of stimulus materials.

5 *Experiment 2*

5.1 *Methods*

5.1.1 *Subjects* Eighteen paid volunteers were assigned to the short SOA group, fifteen to the long SOA group. All subjects had normal or corrected-to-normal vision, and were right-handed (5 with left-handed relatives). The age range was 18 to 25 years and 11 of the subjects were female. None of these subjects had participated in the previous experiment.

5.1.2 *Stimuli* The stimulus materials were the same as those in Experiment 1, with the following exception. ERP subjects were assigned a task other than naming because of the electrical artifacts associated with speech (electromyogram, glossokinetic potential, respiratory potentials, etc.; see [Grozinger, Kornhuber, Kriebel, Szirtes, and Westphal, 1980; Picton and Stuss, 1984] for reviews of these problems). This task was a letter search of the target word performed subsequent to its presentation. Single trials then consisted of the sentences and "target" words as before, but a single letter of the alphabet appeared 1500 msec after each target word. Letters were selected pseudorandomly with the constraint that 50% of each target type were followed by a letter that had been in the word, and 50% by a letter that had not been in the word. ERP responses to these target letters were not analyzed, rather the task was selected solely to insure that subjects attended to the "target" words. We will continue to refer to these words as "targets" for the sake of consistency with Experiment 1, but note that the ERP subjects were not required to make an overt response to these words. It has been shown in previous research that ERPs recorded during such a letter search task reliably discriminate between primed and unprimed words although no behavioral response is required to the words themselves ([Kutas, 1985; see Kutas and Van Petten, in press]). The specifics of stimulus presentation were as in Experiment 1.

5.1.3 *Procedure* Subjects were tested in one session that lasted three to three and a half hours, while reclining in a comfortable chair. They were instructed to read each sentence in order to answer a multiple-choice questionnaire at the end of the experiment, and to read each target word in order to decide if the subsequent letter appeared in the target word. Subjects pressed one of two buttons held in either hand on each trial to indicate "letter present" or "letter absent." Half of the subjects in each group used the right hand for "letter present" and the left for "letter absent," and the other half the reverse.

5.1.4 *Recording System* EEG activity was recorded from ten scalp electrodes, each referred to an average of the left and right mastoids. Eight were placed according to the International 10-20 system at frontal (Fz), central (Cz), parietal (Pz) and occipital (Oz) midline locations, as well as at frontal and central lateral sites (F3, F4, C3, C4). Symmetrical temporoparietal electrodes were placed lateral (by 30% of the interaural distance) and 12.5% posterior to the vertex. Eye movements were monitored via an electrode placed below the right eye and referred to the mastoids for vertical movements and blinks, and via a right-to-left canthal bipolar montage for horizontal movements.

The midline and EOG recordings were amplified with Grass 7P122 preamplifiers (system bandpass 0.01 to 35 Hz, half-amplitude cutoff). The EEG from the lateral scalp leads was amplified with Grass 7P511 preamplifiers modified to have an 8 second time constant (high frequency half amplitude cutoff = 60 Hz).

5.1.4 *Data Analysis* Analog-to-digital conversion of the EEG, EOG and stimulus trigger codes was performed online by a PDP 11/45 computer. A 2048 msec epoch of EEG, beginning 200 msec before the onset of sentence terminal words, was averaged at a sampling rate of 125 Hz. Trials characterized by excessive eye movement or amplifier blocking were rejected, approximately 15% of the trials.

ERPs were quantified by computer as the mean voltage within a latency range, relative to the 200 msec of activity preceding the sentence terminal words. Two latency windows were used to quantify the response to target words. A 300 to 700 msec post-target window was chosen to encompass the usual latency band of the N400 response [Fischler, Bloom, Childers, Roucos, and Perry, 1983; Kutas and Hillyard, 1980a,b,c; McCallum, Farmer, and Pocock, 1984]. A later latency band of 700 to 1100 msec post-target was also measured.

5.2 *Results*

5.2.1 *Filler-Target Responses* The responses to unambiguous sentence completions and subsequent target words at both SOAs are shown in Figure 17.1. It can be seen that the overall waveshape of the response was quite

different at the different SOAs. At the 700 msec SOA, the N100 (negative peak at about 100 msec) and P200 (positive peak at about 200 msec) waves elicited by the terminal word of the sentence were followed by a negative-going anticipatory potential (i.e., contingent negative variation, CNV) before the presentation of the target word, which elicited then similar N100-P200 ERP components. The 200 msec SOA response, in contrast, was a compound ERP in which the responses to terminal and target words overlap.[2]

It is important to note, however, that where the ERP to the terminal words could be isolated, namely in the 700 msec SOA data, there were no differences between the various conditions before the presentation of the target words. This was to be expected since the different conditions included responses from the same sentences counterbalanced across subjects. Therefore, any ERP differences among conditions can be attributed to the target words. It can be seen that the difference between related and unrelated targets at the two SOAs was similar, consisting of greater negativity (an N400) to the unrelated targets. We will focus, therefore, on the relative difference between the ERPs to related and unrelated targets within each SOA.

Long SOA: Figure 17.1 shows that the unrelated targets elicited substantially larger N400s than the related targets. The negative difference between the two target types begins around 300 msec after the target and continues for several hundred milliseconds. The mean amplitudes of each subject's ERPs were subjected to a repeated measures ANOVA using target type (related and unrelated), latency window (300 to 700 msec post-target and 700 to 1100 msec post-target), and electrode site (10 levels) as factors. There was a main effect of target type, $F(1,14) = 8.05$, $p < .02$, reflecting the greater negativity for unrelated targets. There was also an interaction of target type by latency window, $F(1,14) = 5.97$, $p < .03$, reflecting the greater difference between related and unrelated targets in the early (300–700 msec post-target) portion of the waveform than in the late (700–1100 msec post-target). Separate ANOVAs were carried out to test the target type effect within each latency range; the significance of these F-values was evaluated by the Dunnett test. The relatedness effect was significant in both latency windows: early—$F(1,14) = 9.07$, $p < .05$; late—$F(1,14) = 7.03$, $p < .05$.

2 There are two factors which act to make the overall waveshape of the ERP different for the two SOAs. One is a simple superposition, or overlapping, of the ongoing ERPs to the terminal word of the sentence and the target word. An algebraic subtraction routine could, in principle, cancel this superposition effect. However, this is not a tenable procedure for obtaining the "true" ERP to a single word as there are also different physiological/cognitive processes at work in different SOAs. Much research has been devoted to the potentials which develop during the interval between two stimuli presented at a fixed rate (see [Rohrbaugh and Gaillard, 1983] for a review of the CNV). The waveshape and amplitude of these potentials are sensitive to the duration of the interval; we have thus confined our experimental comparisons to within-SOA data.

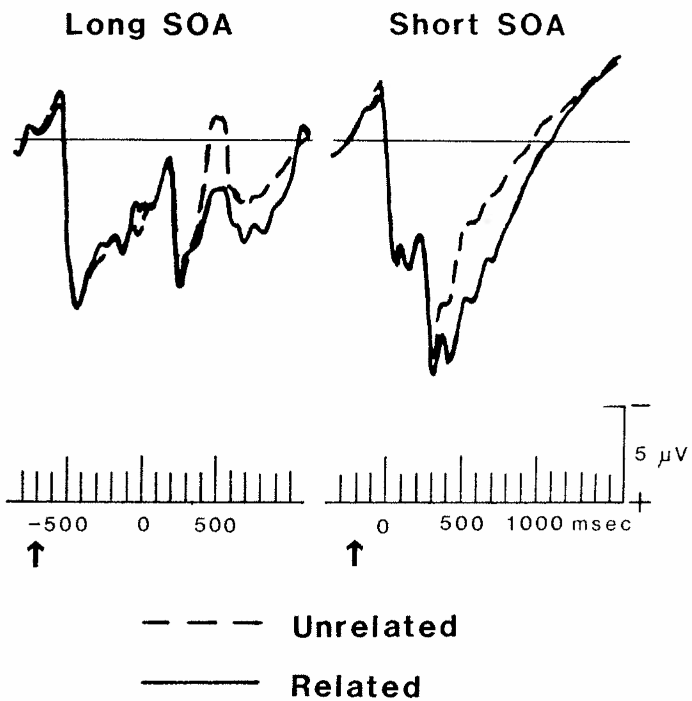

Figure 17.1 Grand average ERPs to unambiguous (filler) sentence terminal words and subsequent targets in the 700 and 200 msec SOA conditions. Onset of the sentence terminal words is indicated by an arrow. Onset of the targets is at 0 msec. The ERPs were recorded at a midline central site (Cz).

Short SOA: ERPs obtained at the 200 msec SOA were similar to those of the 700 msec SOA in that unrelated targets elicited more negativity than related targets beginning about 300 msec after the target word. The ERPs obtained at the 200 msec SOA were analyzed in the same manner as the 700 msec SOA waveforms. There was a main effect of target type, $F(1,17) = 43.9$, $p < .001$, and an interaction between target type and latency window, $F(1,17) = 16.0$, $p < .001$. Separate comparisons showed that unrelated targets elicited greater negativity in both the early, $F(1,17) = 53.6$, $p < .01$, and late, $F(1,17) = 22.9$, $p < .01$, portions of the ERP response.

5.2.2 *Homograph-Target Responses* *Long SOA*: As in the filler data, unrelated targets elicited a large N400 while the contextually appropriate targets (see Figure 17.2). elicited a much smaller N400. The ERP response to contextually inappropriate targets appears very similar to that for the unrelated targets. The mean amplitudes of each subject's ERP were subjected to a repeated-measures ANOVA with target type (3 levels), latency window (2

levels), and electrode site (10 levels) as factors. There was a main effect of target type, $F(2,14) = 8.13$, $p < .002$, but no significant interaction of target type by latency, $F(2,28) = 2.47$, N.S. The main effect of target type in this overall ANOVA is not very informative; the Dunnett test was used to compare the contextually appropriate and contextually inappropriate target responses to the unrelated response. This procedure showed that contextually appropriate target ERPs differed from unrelated target ERPs in both the early and late portions of the response: early—$F(1,14) = 11.3$, $p < .05$; late—$F(1,14) = 8.67$, $p < .05$. In contrast, the inappropriate target responses did not differ from the unrelated response in either portion of the waveform: early—$F(1,14) = 0.21$, n.s; late—$F(1,14) = 0.005$, N.S.

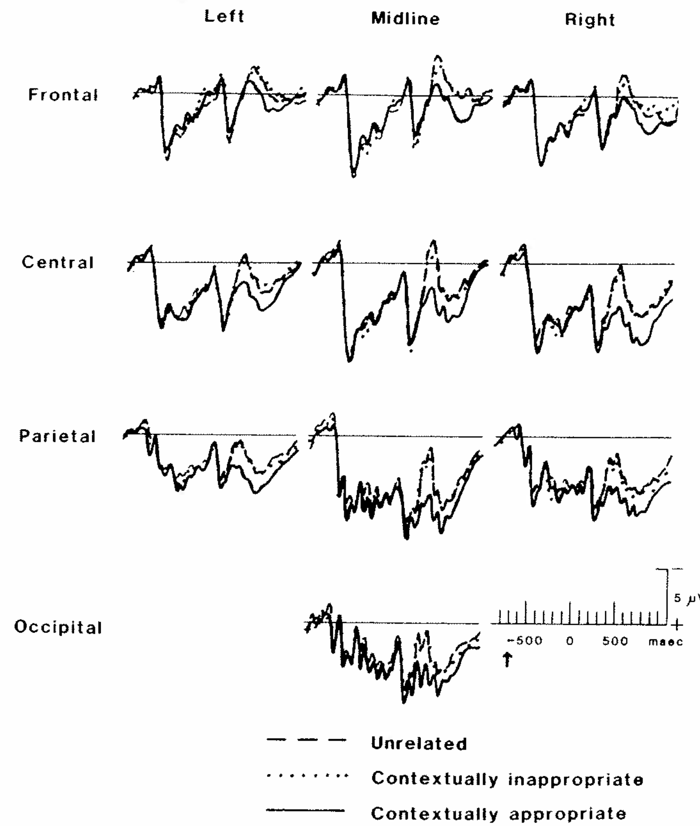

Figure 17.2 Grand average ERPs across electrode sites to homographic sentence terminal words and subsequent targets in the 700 msec SOA condition. Onset of the sentence terminal words is indicated by an arrow. Onset of the targets is at 0 msec.

Short SOA: As in the long SOA data, the unrelated targets elicited a larger N400 than did the contextually appropriate targets. Figure 17.3 shows that the responses to unrelated and contextually appropriate targets begin to separate as early as 300 msec after the target word. Unlike the long SOA data, the response to contextually inappropriate targets does not appear to be identical to the response to unrelated targets throughout the recording epoch. The contextually inappropriate target ERP initially resembles the response to unrelated targets, but subsequently becomes more positive and resembles the response to contextually appropriate targets.

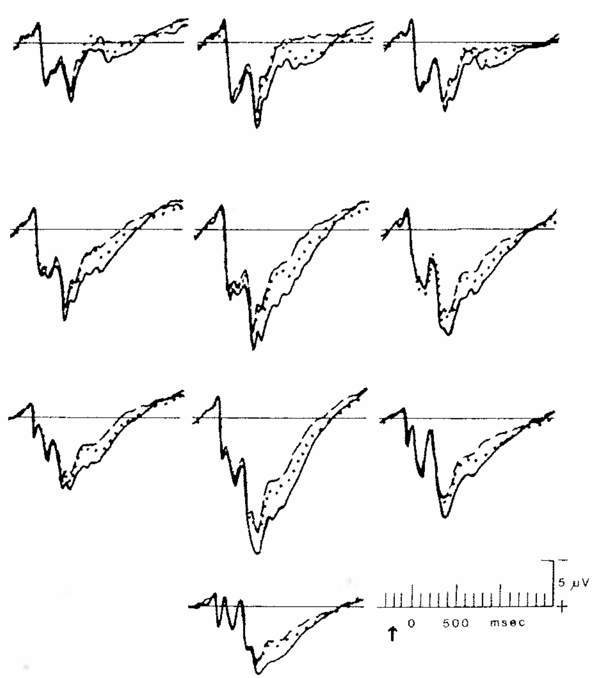

Figure 17.3 Grand average ERPs across electrode sites to homographic sentence terminal words and subsequent targets in the 200 msec SOA condition. Onset of the sentence terminal words is indicated by an arrow. Onset of the targets is at 0 msec.

The ERPs obtained at the 200 msec SOA were analyzed in the same manner as the long SOA ERPs. The overall ANOVA showed significant main effects of target type, $F(2,17) = 18.9$, $p < .001$, and latency, $F(1,17) = 46.5$, $p < .001$. There was also a significant interaction of target type by latency, $F(2,34) = 4.74$, $p < .02$. Pairwise comparisons showed that the contextually appropriate target responses differed from the unrelated in both early and late portions of the waveform: early—$F(1,17) = 52.8$, $p < .01$; late—$F(1,17) = 16.9$, $p < .01$. The contextually inappropriate target responses, in contrast, differed significantly from the unrelated responses in the late portion of the response, $F(1,17) = 13.2$, $p < .01$, but not in the early portion of the response, $F(1,17) = 1.27$, N.S.

Additional *posthoc* tests were conducted on the contextually inappropriate target ERP to further describe its similarity or dissimilarity to the contextually appropriate and unrelated response. Pairwise ANOVAs were computed; F-values evaluated via the Tukey test [Keppel, 1973]. The contextually inappropriate ERP was significantly different from the contextually biased ERP during the 300–700 msec portion of the response, $F(1,17) = 17.7$, $p < .01$. The difference between contextually appropriate and contextually inappropriate responses in the 700–1100 msec latency range, however, failed to reach significance, $F(1,17) = 4.05$, $p < .05$.

It is of some interest to track the time course of the brain responses to the three target types and, in particular, to determine when the contextually inappropriate response deviated from the unrelated response and took on the likeness of the contextually appropriate response. The ERPs averaged across subjects show that the contextually biased response diverges from those to the other two target types at about 300 msec after target onset. The contextually inappropriate response appears to diverge from the unrelated response at about 500 msec following the target. The latency windows originally selected for the analysis of individual subjects' data are, however, too broad to evaluate these impressions about the onset latencies of the experimental effects.

A more fine-grained analysis was provided by comparing successive 25 msec epochs of the responses following presentation of different target types. The 300 to 325 msec epoch was the earliest point at which the contextual target responses differed from the unrelated responses, $F(1,17) = 20.3$, $p < .001$. Similarly, the contextual target responses began to differ from the contextually inappropriate targets in this same time band, $F(1,17) = 9.77$, $p < .01$. This relationship also held for the comparisons between filler related and unrelated targets, $F(1,17) = 5.59$, $p < .05$.

In contrast, none of the comparisons between contextually inappropriate and unrelated target ERPs conducted within the 300 to 500 msec latency region revealed any significant effects due to the semantic relationship between homograph and target. Beginning with the 500 to 525 msec band (and in each 25 msec epoch in the 500 to 700 msec region) there was a significant interaction of relationship type with electrode site, $F(9,153) = 6.08$, $p < .001$. The interaction indicates that for this latency band, the unrelated/contextually inappropriate difference was significant at the three most posterior midline sites only: Cz—$F(1,17) = 5.10$, $p < .05$; Pz—$F(1,17) = 5.38$, $p < .05$; Oz—$F(1,17) = 5.35$, $p < .05$. A significant main effect of target type did not appear until the 700–725 msec band, $F(1,17) = 7.97$, $p < .05$.

In summary, the ERPs to contextually inappropriate targets and to unrelated targets were highly similar during the first 500 msec following the onset of the target. The contextually inappropriate target ERP became more like the contextually appropriate ERP between 500 and 700 msec after the target presentation, and became statistically indistinguishable from the contextually appropriate response in the 700–1100 msec epoch.

5.3 *Discussion*

The present results extend those of previous ERP experiments by demonstrating that the amplitude of the N400 reflects priming across a sentence boundary, as well as priming by a sentence fragment or single word [Bentin et al., 1985; Fischler et al., 1983; 1984; Harbin et al., 1984; Holcomb, in press; Kutas and Hillyard, 1980a,b,c; 1983; 1984; Rugg, 1985]. Targets with no semantic relationship to the final word of a sentence elicit a larger N400 component than do related target words. This relationship between N400 amplitude and priming held for targets following both ambiguous and unambiguous terminal words.

It should be noted that while we speak of fluctuations in the amplitude of a negative wave, the N400, the data can be described in terms of fluctuations in the amplitude of a positive wave in the same latency range. These descriptions are equivalent for our present purposes. The relationship between priming and positivity, or lack of priming and negativity, can be used to test two opposing models of ambiguity resolution. According to the selective access model, contextually inappropriate targets should be processed as if they were unrelated to the preceding ambiguity and so should elicit N400s of equal amplitude, latency, and duration to those elicited by completely unrelated targets at any SOA. The multiple access model, in contrast, predicts that the priming of contextually inappropriate targets is dependent on SOA. In this case, the contextually inappropriate target ERP should be identical to the contextually appropriate target ERP at the short SOA when both senses of the ambiguity are still activated, and identical to the unrelated ERP when a longer interval allows selection of the contextually appropriate meaning.

Our finding of equivalent N400s for contextually inappropriate and unrelated targets at the long SOA is compatible with either the multiple or selective access model. On the other hand, the ERPs obtained with the 200 msec SOA do not fit neatly into the pattern predicted by either model. We cannot accept the selective access model in its simplest form because the contextually inappropriate and unrelated ERPs at the short SOA do differ. The greater positivity of the contextually inappropriate ERP as compared to the unrelated one suggests that the contextually inappropriate targets were, at some point, processed in a manner similar to contextually appropriate targets. However, the ERPs to unrelated and contextually inappropriate targets do not differ until 500 msec have passed since the presentation of the target. In contrast, the ERPs to unrelated and contextually appropriate targets differ as early as 300 msec post-target. The 200 msec lag between the onset of these two effects is not consistent with the multiple access model of simultaneous and parallel activation of both senses of ambiguous word.

How can we account for the existence, but late onset, of the contextually inappropriate/unrelated target difference? Some possible interpretations must be discounted by the lack of any difference between unrelated and contextually inappropriate targets in the long SOA condition. For instance, if the late priming-related positivity was due to the delayed realization that the contextually inappropriate targets *were* related to the homographs, although not in the way originally expected, there should be a similar "double take" effect some 500 msec after the target in the long SOA condition. There was not. Similarly, one might suppose that the subjects engaged in a deliberate attempt to recover the contextually contextually inappropriate meanings of the homographs (after the experiment, several subjects in both SOA conditions reported noticing these), and that the late effect is the product of slow strategic priming of the sort described by Neely [1977]. Although subjects in the long SOA condition had more time to engage strategic or attentional processes, their brain responses did not differentiate between contextually inappropriate and unrelated targets. Thus, this explanation seems unlikely.

Finally, it has been suggested that the differing onset latencies of the priming effects we report for contextually appropriate and inappropriate targets reflect the targets' differential relationships to intermediate sentence words, rather than their relationships to the terminal homographs. Many of the contextually appropriate targets had semantic relationships to intermediate words while the contextually inappropriate targets did not.

In this view, the priming effect for contextually appropriate targets might be composed of two parts: an early part (onset at 300 msec post-target) due to direct priming by intermediate words, and a late part (onset at 500 msec) due to priming by the terminal homograph. The apparently different onset latencies for priming of contextually appropriate and inappropriate targets would only reflect the fact that contextually inappropriate targets lack the early, intermediate-word component of the priming effect. If this were true, the present results might reflect equal and simultaneous priming of both target types by the terminal homographs, thus supporting the multiple access hypothesis. We find this explanation unlikely, although logically possible, because 500 msec seems very long for the *onset* of a forward priming effect.

It is not possible to refute this proposal via analysis of the ERPs to homograph targets. The intermediate word—target relationships were a necessary consequence of our effort to construct constraining sentence contexts for the homographs. Note however, that this alternative explanation is not specific to sentences with ambiguous words, but makes general predictions about the onset latency of the ERP priming effect for targets which have been primed solely by the terminal word of a sentence. A substantial proportion of the filler sentences contained no intermediate words related to the filler targets (see Appendix 2). According to the proposal outlined above, the priming effect for the related targets of these sentences should onset at the same time as the priming effect for the contextually inappropriate targets of homograph sentences.

Filler sentences were thus split into two conditions, "high associative context" and "low associative context" and the ERPs to related targets following "low context" fillers averaged separately for the subjects in the short SOA group. For each subject, 38 of the original 60 related targets fell into this condition.[3] Figure 17.4 compares the ERP difference wave (priming effect) for "low associative context" fillers with those for contextually related and contextually inappropriate homograph targets. It can be seen that the "low context" filler effect substantially precedes the contextually inappropriate target effect, although it does begin slightly later than the priming effect for contextually appropriate targets. The onset latency of the "low context" filler priming effect was determined in the same manner as latencies in the other conditions (see Results). The first time window in which these related and unrelated targets differed was 350–375 msec post stimulus, $F(1,17) = 10.9$, $p < .004$. The 50 msec lag between the onset of this priming effect and that for the contextually appropriate targets of homographs may well be due to the lack of intermediate word priming. This small latency shift cannot, however, account for the much longer delay in priming of contextually inappropriate homograph targets. The 500 msec onset of this priming effect is clearly much later than the normal onset latency for priming by sentence terminal words.

The hypothesis most consistent with our results is that backward priming of the type reported by Kiger and Glass [1983] occurred in the 200 msec SOA but not in the 700 msec SOA condition. It seems reasonable to assume that there was greater temporal overlap between terminal word and target word processing in the short SOA condition than in the long SOA condition. Thus, target words presented shortly after the terminal words might have served as second sources of context in the as yet incomplete interpretation of these words. When the terminal words were ambiguous, contextually inappropriate targets

3 The remaining 22 trials constituting the "high associative context" condition were insufficient for an adequate signal-to-noise ratio in averaging the ongoing electroencephalogram to form an ERP. The "low associative context" condition is, however, of greater relevance here.

could have served to activate the sense of the word which had not been primed by the preceding sentence. The concurrent processing of this newly activated meaning and its related target would, in this view, have led to the observed priming effect for the contextually inappropriate targets. One would expect such mutual priming between the ambiguity and its contextually inappropriate target to lag behind priming between the ambiguity and its contextually appropriate target because the former requires *de novo* activation of a new meaning for the ambiguity while the latter can draw on the previously established sentence context.

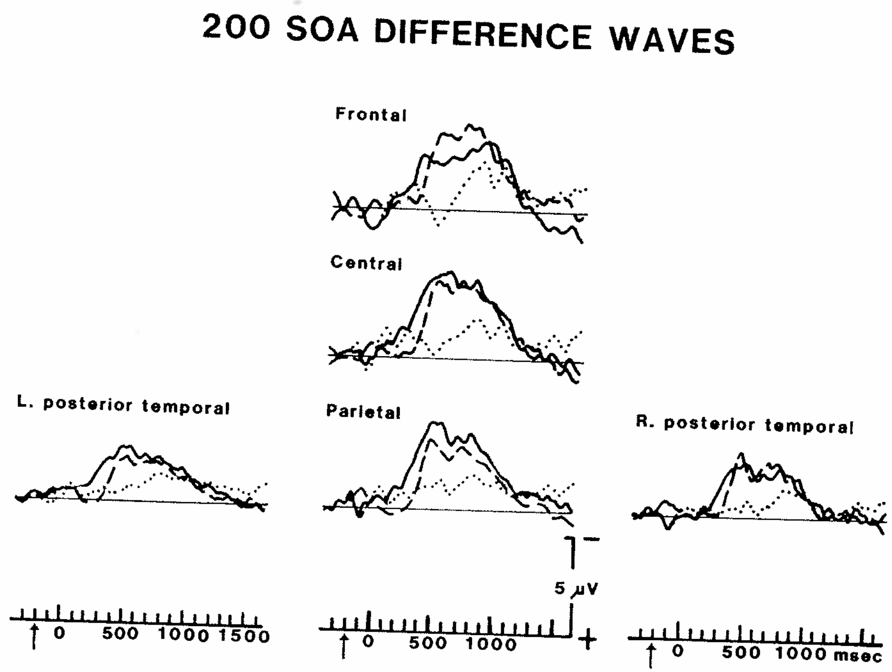

Figure 17.4 Grand average difference waves for the 200 msec SOA. Onset of the sentence terminal words is indicated by an arrow. Onset of the targets is at 0 msec. The solid line is the result of subtracting the ERP to contextually appropriate targets from the ERP to unrelated targets following homographs. The dotted line is the result of subtracting the ERP to contextually inappropriate targets from the ERP to unrelated targets following homographs. The dashed line is the result of subtracting the ERP to related targets following filler sentences of low associative context (see text) from the ERP to unrelated filler targets. Copyright © 1987 by Academic Press, reprinted by permission.

This interpretation of the present results is consistent with one tenet of the multiple access model of ambiguity resolution: it takes some time to process an ambiguous word. It is inconsistent with the tenet that one stage of such processing involves the simultaneous activation of both senses of the ambiguity. Rather, it suggests that there is an early stage of ambiguity resolution in which the ambiguity can be *reinterpreted* due to the additional context provided by a subsequent word. At some later time, a final interpretation has been found and the ambiguous word is immune to further context effects.

6 Conclusions

We believe that the backward priming interpretation of the ERP data obtained in Experiment 2 is also compatible with the naming latency data reported for Experiment 1. A direct comparison between the behavioral reaction time and ERP onset latencies is not feasible because these were obtained from different subjects. However, it is important to note that the first ERP indication of a differentiation between contextually inappropriate and unrelated targets in one group of subjects precedes the behavioral response of the other group of subjects. Naming latencies hovered around 600 msec in the short SOA condition of Experiment 1 (see Table 2). At this point in time, mutual priming between ambiguities and their contextually inappropriate targets may already have taken place so that the reaction time to such targets would reflect this benefit.

This backward, or mutual, priming interpretation of RT data which appear to reflect multiple access is supported by evidence obtained from a new reaction time technique which Glucksberg and his colleagues have recently applied to the problem of ambiguity resolution. These investigators have used a variant of the lexical decision task in which RT for nonwords rather than words is the dependent variable. Nonwords are constructed so as to be reminiscent of true words, such as "piamoe" and "kidnea" from "piano" and "kidney," respectively. In a simple word-pair task, subjects are slower to reject 'related' nonwords such as "piamo" or "kidnea" following "organ" than 'unrelated' nonword controls such as "moepia" or "nedika." This interference is, however, asymmetric. "Organ" influences reaction time for "piamoe," but the presentation of "piamoe" neither facilitates nor inhibits the lexical decision to "organ" [Gildea, 1984]. The unidirectional nature of this interference effect was used to construct a lexical ambiguity paradigm which was insensitive to backward priming effects. Reaction time interference was found for only the contextually 'related' nonword targets following ambiguous words in a biasing context [Glucksberg, Kreuz, and Rho, 1986].

Glucksberg's nonword version of the lexical decision paradigm appears to eliminate the possibility of backward priming even at short prime-target SOAs.

Since only real word targets were used in the experiments reported here backward priming was not eliminated. Instead we relied on the temporal resolution of the event-related potential measure to distinguish forward from backward priming by their different time courses. The study of this sort of backward (mutual) priming may, in the long run, reveal much about the nature and tem poral characteristics of the integration of single word meanings into discourse.

Acknowledgments

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Appendix 1

Homograph	Contextually Appropiate Target	Contextually Inappropriate Target
bail	bucket	money
bank	river	account
bats	vampire	baseball
bear	carry	grizzly
bill	beak	pay
bit	chew	piece
blues	rhythm	sky
bluff	cliff	fake
bow	stern	kneel
bowl	ball	soup

Homograph	Contextually Appropiate Target	Contextually Inappropriate Target
box	fight	cardboard
bridge	cards	river
bug	spy	insect
cabinet	president	cupboard
calf	leg	cow
can	tin	can't
capital	money	washington
change	alter	dollar
check	over	cash
chest	box	body
china	japan	dishes
club	group	hit
coach	carriage	football
coast	beach	roll
count	duke	ten
court	tennis	law
date	girl	day
deck	cards	ship
deed	title	act
draft	tap	army
draw	tie	sketch
fall	winter	down
fan	follower	cool
fence	sword	wall
file	nail	folder
gin	rummy	vodka
glasses	drinks	lenses

Homograph	Contextually Appropiate Target	Contextually Inappropriate Target
grate	grill	cheese
ground	grind	floor
hide	skin	seek
key	note	lock
leaves	goes	trees
litter	kittens	trash
lot	acre	plenty
march	april	walk
match	same	light
may	june	might
means	thinks	average
miss	hit	mrs
nag	horse	bitch
nails	fingers	hammer
nut	bolt	seed
organ	liver	piano
palm	tree	hand
park	car	bench
pass	mountain	fail
pen	pig	ink
pick	shovel	choose
pipe	smoke	water
pit	hole	peach
pitch	tone	throw
pitcher	beer	baseball
plant	factory	green
play	stage	game
plot	land	story

Homograph	Contextually Appropriate Target	Contextually Inappropriate Target
poker	fireplace	cards
pool	table	swim
port	wine	harbor
pot	soup	marijuana
pound	weigh	beat
present	give	future
press	news	push
punch	fruit	hit
pupils	eyes	students
race	color	run
refrain	chorus	stop
rest	remainder	sleep
ring	bell	finger
rose	stood	flower
row	line	paddle
ruler	measure	king
rung	rang	ladder
saw	ax	look
scales	fish	weigh
second	minute	third
sentence	prison	paragraph
shed	tool	fur
sink	swim	kitchen
slip	dress	slide
slugs	worms	hits
solution	mixture	problem
spade	ace	shovel

Homograph	Contextually Appropriate Target	Contextually Inappropriate Target
spoke	wheel	talked
spring	jump	summer
squash	racquet	vegetable
stall	delay	barn
star	movie	planet
sticks	stay	stones
stock	cattle	exchange
story	floor	read
straw	hay	sip
swallow	bird	drink
table	figure	chair
tank	gas	guns
temples	head	jewish
tick	flea	tock
tie	win	knot
till	soil	cash
tip	turn	waiter
tire	sleep	car
toast	drink	bread
toll	chime	fee
top	spin	bottom
train	practice	freight
volume	book	sound
wake	wave	sleep
watch	look	wrist
will	testament	won't
yard	inches	front
amount	art	call

Unrelated targets		
chain	classic	curly
doll	echo	final
glad	glum	guru
held	honor	hope
keep	lips	mineral
modern	nature	never
parent	pie	pill
poetry	proof	quotes
risk	scare	school
score	sell	shine
shown	smile	soon
steam	threat	trigger
understood		

Note: the same 40 unrelated targets were used for each of the three stimulus lists.

Appendix 2

Low Associative Context Fillers and Related Target Words

He almost got lost driving home because it was so foggy.
clear

The interview went well and he got the job.
work

It was a dark and stormy night.
day

He admitted that he was wrong.
right

Low Associative Context Fillers and Related Target Words

He thought the most important issue in the election was peace.
war

She was afraid to walk alone after dark.
light

The library kept very short hours and seemed to usually be closed.
open

He glanced out the window and saw that it was a beautiful day outside.
inside

She wanted to find the owner of the dog she had found.
lost

They stayed home and watched an old movie on TV.
radio

She had lost her comb.
hair

The professor gave a surprise quiz.
test

She didn't want to travel in Mexico until she had learned Spanish.
language

The scientist had proven the old theory to be false.
true

They told him the check was in the mail.
letter

He was planning on winning the lottery and becoming rich.
poor

He had never learned to swim and tried to stay where the water was shallow.
deep

She made a point of arriving early.
late

The sun didn't set until ten in the evening.
morning

He wrote a note to himself so that he wouldn't forget.
remember

Low Associative Context Fillers and Related Target Words

He left yesterday.
today

He got paid twice a month.
week

The geese were flying south.
north

He painted his kitchen white.
black

He lifted weights but still thought he was weak.
strong

Most truck drivers belong to the Teamsters.
union

He had made many political enemies.
friends

His speech lasted only ten minutes.
hours

She let the phone ring six times but there was no answer.
question

He had trouble eating and sleeping when he was under pressure.
stress

The mountain is twelve thousand feet high.
low

She had always wanted to sail to Hawaii.
island

He was sorry to hear that the old man was dying.
dead

His uncle wanted to know why he hadn't settled down and gotten married.
single

He didn't believe that his friend would have told him a lie.
truth

She had moved to New York.
city

Low Associative Context Fillers and Related Target Words

The shepherd led his flock to the summer pasture.
field

The man looked very familiar but she couldn't remember his name.
face

The convict tried to get a special pardon from the governor.
state

You could tell by his accent that he had grown up in the east.
west

He wouldn't show his work to anyone until it was finished.
start

The little boy promised Santa Claus that he had been good.
bad

She bought a stuffed toy for her granddaughter.
grandson

He is always careful to wear his seat belt.
buckle

He took four aspirin.
headache

She was teaching her dog to beg.
plead

He thought the cake was too sweet.
sour

He wanted a roommate who would be quiet and neat.
sloppy

The first thing she reads in the Sunday paper is the comics.
cartoons

The airline had lost her suitcase.
luggage

Every muscle in his body ached.
sore

They made camp just before sunset.
sunrise

Low Associative Context Fillers and Related Target Words

He had forgotten the words to the song.
tune

They went to the zoo to watch the apes.
monkey

She never paid any attention to the gossip.
rumor

The kids had a great time at the circus.
clown

The usher was collecting tickets at the entrance.
exit

He bought a quart of milk and a dozen eggs.
bacon

He was wearing a down jacket and mittens.
gloves

They wouldn't let her into the restaurant because she wasn't wearing shoes.
socks

He ordered french fries with his hamburger.
hotdog

She spent many years with an Indian tribe and wrote down many of their stories and legends.
myths

He bought a spool of thread and some needles.
pins

She was afraid of spiders.
web

The medical students had to memorize all of the major arteries.
veins

He got drenched walking in the rain.
umbrella

They couldn't agree on what kind of ice cream to buy and finally settled on vanilla.
chocolate

Low Associative Context Fillers and Related Target Words

The sweater was knitted from blue and grey wool.
lamb

He refused to clean the kitchen because it wasn't masculine.
feminine

He woke up screaming from a bad dream.
nightmare

Everything she owned was in a brown paper bag.
sack

The hunter dropped his rifle.
shotgun

Her car broke down in the desert and she had to hitchhike.
thumb

They were out of dish soap.
suds

They had a big family dinner every Thanksgiving.
turkey

When he cleaned his desk he threw most of his old notes into the trash.
garbage

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