EVENT-RELATED BRAIN POTENTIALS (ERPs) MEASURE THE INFLUENCES OF ORTHOGRAPHIC, PHONOLOGICAL AND SEMANTIC REPRESENTATIONS DURING SILENT READING

by

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DEDICATION

This thesis is dedicated to the memory of my brother, James Henry Forbes, who died in 1982 of a massive head injury after being hit by a drunk driver.

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Abstract

The degree to which phonological codes influence the word identification process has been debated. Event-related brain potentials (ERPs) have been used to investigate the processes involved in language. The N400 is a negative-going neural component that occurs approximately 400 ms post-stimulus. This component has been shown to be sensitive to semantic priming and occurs reliably to semantically incongruous, and therefore unexpected, terminal words of sentences. A series of sentences with high contextual constraint were visually presented in each of the four experiments. ERPs were recorded to the sentence-ending stimuli which completed the sentences in either a congruous or incongruous manner. Each of the 4 experiments investigated whether phonological codes influenced sentence reading when factors shown to diminish this effect in behavioural tasks were introduced. Phonologically ambiguous words (i.e., homophone foils) or non-words (i.e., pseudofoils) were used in each experiment to measure the effect of phonological recoding. The results of these studies showed that the N400 component responded differentially to semantically unexpected sentence-ending stimuli. This differential response depended upon whether or not they were phonologically identical to the high cloze probability words for the sentences. The N400 responses that were elicited by phonologically unexpected stimuli were significantly larger than those elicited by phonologically expected lexical and non-lexical stimuli. One exception to this pattern was observed in Experiment 1 when subjects performed a semantic judgement task and incongruous terminal words produced N400 responses regardless of whether they were phonologically expected. The evidence for phonological recoding was not attributable to orthographic similarity. However, some evidence was obtained which suggested that an earlier occurring negative-going component, the N270, was sensitive to deviations in orthographic expectancy for the sentence-ending stimuli. Overall, these findings demonstrate that ERPs are useful for investigating the subtle processes involved in language. Further, these results support theoretical models that propose an important role for phonology during word recognition.

Abbreviations and Symbols

ERP	event-related brain potential
EEG	electroencephalogram
ms	millliseconds
µV	micro-volts
Hz	Hertz
EOG	electro-oculogram
SD	standard deviation
M	mean
KΩ	kilo-ohm
ANOVA	analysis of variance
PIAT-R	Peabody Individual Achievement Test - Revised
WRAT-3	Wide Range Achievement Test - 3

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Chapter One

Behavioural evidence for phonological recoding

The processes through which written words are identified are very complex. The investigation of these processes has generated a great deal of interest throughout the history of cognitive research. Several models have been developed in an effort to understand the means through which printed text is able to access the semantic representation (i.e., meaning) of words. Essentially, all of these models propose that word identification proceeds through the use of orthographic, phonological and semantic codes. However, the extent to which each of these codes influences the word identification process has been a long-standing issue of debate. In particular the role of phonology in identifying printed words has been a contentious issue.

One of the major theories of visual word recognition is the dual-route theory (e.g., Coltheart, 1978, 1985; Coslett, 1991; Behrmann & Bub, 1992; Funnell, 1983). This theory has proposed a model which depicts the processes involved in word identification. While this model has received its share of criticisms by researchers who are proponents of other theoretical models (e.g., Glushko, 1979; Marcel, 1980; Seidenberg & McClelland, 1989; Van Orden, Pennington & Stone, 1990) a great deal of empirical evidence in support of the dual-route model has been reported (e.g., Herdman & Beckett, 1996). Consequently, it is currently the most widely accepted model of visual word recognition (e.g., Coltheart, Curtis, Atkins & Haller, 1993; Behrmann & Bub, 1992; Herdman & Beckett, 1996, but see Humphreys & Evett, 1985).

Many versions of the dual-route theory have been proposed. While there are subtle differences between these dual-route models they all share the same basic assumption. The fundamental property that is proposed by all dual-route models is that there are two routes through which words can be identified. In addition, both routes share a common process insofar as the visual presentation of a word results in the activation of an orthographic representation. However, the manner in which the orthographic representation is activated has been debated.

On one hand, Smith (1971) has proposed that the wholistic features that are associated with the visual representation of a word are extracted and then used to access the appropriate lexical representation. According to Smith the orthographic code represents the word in its entirety. That is, the orthographic representation that is activated is associated with the whole word rather than with any particular part of it. This position has been supported by more recent research investigating the role of orthography in the word identification process (Buchanan & Besner, 1993).

On the other hand it has been suggested that the orthographic representation that is associated with a particular word is parsed into several components. These components are then responsible for activating the stored lexical representations that are associated with the word (Evett & Humphreys, 1981). This approach has received support from Reggia, Marsland and Berndt (1988) who suggest that the orthographic representations associated with the lexical route are parsed into different components. These components are thought to reflect the phonemic units of the word. Overall, these findings suggest that orthographic codes access the stored lexical representations during the word identification process (e.g., Grainger & Ferrand, 1996; Ferrand & Grainger, 1993; Baluch, 1993) however the exact manner in which the orthographic characteristics are activated during the word identification process is currently undetermined.

Although both routes depicted by the model involve activating orthographic representations these routes differ in terms of the knowledge base that they are believed to represent (Coltheart et al., 1993; Humphreys & Evett, 1985). Whereas the first route is believed to represent word-specific knowledge the second route is thought to represent abstract spelling-to-sound rules. This difference has important implications for the manner in which word identification occurs in each route. Moreover, the extent to which phonology influences visual word recognition is proposed to differ between the routes.

The first route, referred to as the lexical route, is presumed to represent word-specific knowledge. Word identification occurs in this route via a direct mapping of the visual representation (orthographic representation) of a word to its lexical representation that is stored in the mental lexicon. That is, during the word identification process orthographic representations are activated by the presentation of the word that is to be identified. These orthographic representations in turn activate the lexical representation of words that have been previously encountered. Since the lexical representation is activated directly by the orthographic representation this route identifies words in much the same way as one might look-up a word in the dictionary. Following this, phonological representations are activated which may be used to aid the integration of newly acquired information (Coltheart, 1978; Daneman & Reingold, 1993; Baddeley, 1979; Levy, 1977).

In contrast to the first route which is thought to represent word specific knowledge, the second route is thought to represent a series of abstract spelling-to-sound rules. The second route is referred to as the non-lexical route insofar as the use of these spelling-to-sound rules is not dependent upon word-specific knowledge. Rather, the orthographic representation that is activated by the visual presentation of a word activates a phonological representation. This phonological representation then activates the lexical representation that is associated with the word.

According to the model each of the letters in a letter string is associated with a separate phonemic representation. The mapping of the individual letters onto a phonological representation would proceed according to a set of basic rules that depict the relationship between orthography and phonology. This approach is referred to as the grapheme-to-phoneme conversion (i.e., GPC) (Venezky, 1970). Since the orthographic representation of a word can be mapped onto a phonological representation according to the spelling-to-sound rules this process can be used to determine the pronunciation of unfamiliar words or nonwords. Much support for this proposal has been reported by researchers (Coltheart, Besner, Jonasson & Davelaar, 1979; Stanovich & Bauer, 1978; Pring, 1981).

Therefore, the dual-route model presumes that orthographic, phonological and semantic codes are involved in the word identification process. However, the extent to which orthographic and phonological codes influence the activation of semantic codes has been a long-standing issue of debate. While most researchers would agree that the visual representations of the words (i.e., orthographic codes) assume a critical role in this process there is not a consensus with regard to the role that the phonological codes may have in identifying words. The question is whether phonological codes have an integral role in the identification of words (e.g., Lukatela & Turvey, 1994a, b; Van Orden et al., 1990; Ferrand & Grainger, 1994) or if they are involved in integrative processes that occur after word identification has been achieved (e.g., Daneman & Reingold, 1993; Levy, 1977).

Although the dual-route model has proposed a role for phonology during word identification some researchers argue that word recognition is most likely to occur via the lexical route. This position is based upon the rationale that the processing time associated with the non-lexical route would be longer than that associated with the lexical route because of the involvement of phonology (Evett & Humphreys, 1985). Insofar as both routes operate in parallel the word identification process would be completed sooner by the lexical route than it would be by the non-lexical route. Consequently, phonological codes would not assume a critical role in the word identification process.

Studies investigating the influence of phonology on the word identification process has produced contradictory findings. That is, while some researchers have reported evidence suggesting a role for phonology during word identification other researchers have reported evidence that indicates a lack of phonological influence. However, these inconsistencies have been interpreted by other researchers as evidence suggesting that task requirements can influence the extent to which phonological codes are used during the word identification process (Grainger & Ferrand, 1996; Ferrand & Grainger, 1996; Bentin & Ibrahim, 1996; Bentin, 1989; Waters, Caplan & Leonard, 1992; Coltheart, Avons, Masterson & Laxon, 1991; Van Orden, 1987; Coltheart, Patterson & Leahy, 1994; Jared & Seidenberg, 1991; Davidson, 1986; Daneman & Stainton, 1991; Coltheart, 1978; Martin, 1982; McNamara & Healy, 1988; McQuade, 1981). Even though the role of phonology during word identification has been studied using a range of experimental paradigms it is difficult to draw general conclusions with regard to the typical use of phonological representations in this process.

Moreover, there has been some difficulty in defining the exact nature of the phonological codes. This is reflected in the use of various labels to describe certain aspects of the influence (e.g., speech recoding, phonetic recoding, phonemic recoding and deep phonemic recoding) (McCusker, Hillinger & Bias, 1981). Since the present series of studies is primarily concerned with whether or not phonology influences the reading process rather than what the exact nature of the influence might be, the general term "phonological recoding" will be used. The term "phonological recoding" is intended to reflect the recoding of the orthographic information into a phonemic code that may be used to activate stored lexical representations. The term phonological recoding in this context refers to any internal representations associated with auditory, articulatory, phonetic and phonemic information (Van Orden, 1987).

<u>Phonological Influences during Word Identification</u>

Phonological recoding has been investigated in recent research by manipulating the phonological codes that are associated with both words and non-word stimuli. Homophones are frequently used to study phonological recoding during visual word recognition (e.g., Daneman & Stainton, 1991; Van Orden, 1987; Galbraith & Taschman, 1969). Homophones are two words with identical pronunciations but that differ in terms of their derivations, meanings and spellings (Kreuz, 1987). These words offer a unique opportunity to study phonological recoding because of their ambiguous nature.

The phonological representations that are associated with pronounceable non-word stimuli have also been used to study phonological recoding. Non-word stimuli that share their phonological representations with real words have been used to investigate phonological recoding. Insofar as these stimuli, referred to as pseudohomophones, are phonologically identical to, but orthographically different from, real words they can be used to examine the phonological influences during word recognition that occur independently from orthographic influences. The effect of including these pseudohomophones in a task is often compared to the effect observed with another type of non-word stimuli that do not share either their phonological or orthographic representations with any real words. These stimuli, typically referred to as simply non-words, are used as a basis for comparison with pseudohomophones. Insofar as only the pseudohomophones share their phonological representations with real words any differences that are observed between these two types of non-lexical stimuli may be attributed to phonological mediation during the experimental tasks. Thus, phonological recoding is typically examined using lexical and non-lexical stimuli that are phonologically ambiguous in nature.

As mentioned previously, several methodological approaches have been used to study phonological influences under different experimental conditions. The various paradigms typically examine these influences by manipulating the phonological representations of the stimuli that are presented during the task. The effects of these manipulations are often interpreted through the use of behavioural measures such as reaction time and response accuracy. The differences that are observed between the stimulus conditions in terms of these behavioural measures are indicative of the phonological influences that occur during the word identification process.

Whether the pattern of behavioural results supports the position that phonological codes influence the word identification process depends upon the experimental paradigm that is used.

On one hand evidence that phonological influences hinder task performance has been obtained. This effect of phonology has been inferred from the longer reaction times and higher error rates that are associated with phonologically ambiguous stimulus conditions than with other stimulus conditions. The differences between these stimulus conditions have been taken to suggest that the phonologically ambiguous stimuli are more difficult to process than the stimuli in the other stimulus conditions. Consequently, these stimuli require more time to process and subjects make more errors when decisions regarding these stimuli must be made.

On the other hand, evidence that phonological representations can facilitate performance has also been observed. In this case, phonologically ambiguous stimuli have shorter reaction times and lower error rates than stimuli from other stimulus conditions. The difference between the stimulus conditions is assumed to be due to the facilitatory effect of using phonological codes during the word identification process. Given that phonological influences during the word identification process vary with the experimental task, the influence of phonology during the word identification process must be interpreted within the context of the experimental paradigms used to investigate the effect.

Lexical decision tasks are commonly used to examine the influence of phonology during word recognition. During these tasks subjects are presented with a series of letter strings. After each letter string is presented, the subjects are required to decide whether it constitutes a word or a non-word. Since it is possible to manipulate the phonological representations of the letter string this particular paradigm is useful for investigating phonological recoding during the processes involved in deciding whether a letter string is a word.

Much of the research involving lexical decision tasks has provided evidence in support of phonological recoding. One of the first studies to investigate phonological recoding using a lexical decision task was conducted by Rubenstein, Lewis and Rubenstein (1971). In their study the subjects were presented with a series of letter strings that were either real English words or were non-words. There were two types of non-word stimuli that were presented in the stimulus set. The non-words either shared their phonological representations with real English words (i.e., pseudohomophones) or they did not (i.e., non-homophonic non-words).

The subjects were required to decide whether each of the letter strings was or was not a real English word. It was predicted that the phonological codes that were associated with the pseudohomophones would interfere with the subjects' decision making ability making it more difficult to decide whether the stimuli were words or non-words. The differences between these stimuli were expected to be reflected in the behavioural measures. The results of the study were consistent with this hypothesis.

The reaction times that were associated with the pseudohomophones were significantly longer than those associated with the non-homophonic non-words. Further, the same pattern of performance was observed in the error data: significantly more errors were made to the pseudohomophones. Insofar as the stimuli in both of these conditions were non-words it is reasonable to conclude that the latency and accuracy differences between these conditions were due to phonological recoding. These results were supported by data from several studies (e.g., Martin, 1982; Hawkins, Reicher, Rogers & Peterson, 1976; McQuade, 1981; Davelaar, Coltheart, Besner & Jonasson, 1978; Meyer, Schvaneveldt & Ruddy, 1974; Bias & McCusker, 1980).

In a more recent study Perfetti, Bell and Delaney (1988) investigated the influence of phonology during a word identification task. In contrast to the Rubenstein et al. (1971) study which predicted that phonological recoding would interfere with word identification Perfetti et al. (1988) predicted that the use of phonology would facilitate this process. In Perfetti et al.'s (1988) study a series of English words was presented and the subjects were asked to identify them. Each of the words, referred to as targets, was briefly presented and was immediately followed by a non-word mask.

The non-word masks were presumed to interfere with the early stages of processing that are involved in word identification (Turvey, 1973). That is, the masks were expected to disrupt the orthographic representation that was activated by the presentation of the words. Three types of non-word masks were presented. In comparison to the targets, the non-word masks were either 1) orthographically similar and phonologically identical, 2) orthographically similar and phonologically different or 3) both orthographically and phonologically different. In addition several 'blank' trials were introduced in which the non-word mask was presented in the absence of a target. These trials were included so as to discourage subjects from guessing the identity of the targets from the presentation of the non-word masks.

It was hypothesized that the subjects' ability to identify the targets would be facilitated when the targets were followed by non-word masks with a common phonological representation. The results of the study supported this prediction. The targets that were followed by phonologically identical non-word masks were recognized significantly more frequently than the targets that were followed by orthographically similar but phonologically different masks. Furthermore, the targets that were followed by both of these types of non-word masks were recognized significantly more frequently than were the targets that were followed by the orthographically and phonologically different non-word masks. Insofar as the highest level of response accuracy was associated with the phonologically identical non-word masks, these findings were interpreted as evidence that supports the role of phonology in the word identification process.

However, the results can also be interpreted as evidence suggesting that non-word masks that were orthographically similar to the targets facilitated task performance. That is, the non-word masks that were orthographically similar to but phonologically different from the targets facilitated task performance in comparison to the non-word masks that differed both orthographically and phonologically from the targets. Inasmuch as the orthographic representations appear to have influenced task performance it is possible that the facilitatory effect observed in the stimulus condition involving orthographically similar and phonologically identical non-word masks is largely due to the orthographic similarity shared between the targets and the non-word masks. If this were true then whether the phonological representations assumed a critical role during the word identification process remains unclear.

This position is supported by research conducted by Brysbaert and Praet (1992) which attempted to replicate the findings of Perfetti et al. (1988) in Dutch. Although Brysbaert and Praet (1992) succeeded in replicating the general findings of Perfetti et al. (1988) in their first experiment they identified a possible confounding variable in the research. That is, Brysbaert and Praet (1992) noted that in the 'blank' trials subjects had guessed the identity of the targets from the masks. Insofar as there were no targets presented in the 'blank' trials this finding suggested that task performance on the critical trials was influenced by guessing the targets' identity from the presentation of the masks.

A second experiment was conducted by Brysbaert and Praet (1992) which was intended to discourage subjects from guessing the identity of the targets. In this experiment the extent to which the orthographic representations of the targets and non-word masks overlapped was minimized by reducing the number of letters that the pseudohomophones shared in common with the targets. In addition, the stimuli were counterbalanced across subjects so that only one type of non-word mask was presented with each target rather than all subjects being exposed to all possible combinations of the non-word masks with each of the targets as was done previously.

The results of this experiment differed from those obtained both in Experiment 1 and by Perfetti et al. (1988). The results indicated that the orthographically similar non-word masks were associated with significantly higher levels of accuracy than were the non-word masks that differed both orthographically and phonologically from the target words. This effect was observed regardless of whether the non-word masks were phonologically identical to or different from the target words. Furthermore, the frequency with which the targets identity was guessed from the presentation of the non-word masks was greatly reduced.

These findings were interpreted as evidence indicating that Perfetti et al.'s results were confounded by subjects trying to guess the identity of the targets. Moreover, these results indicated that the non-word masks that were phonologically identical to the target words did not facilitate task performance beyond the level of facilitation that can be attributed to orthographic representations. Thus, Brysbaert and Praet (1992) concluded that phonology did not assume a critical role in the word identification process in neither their study nor that of Perfetti et al. (1988).

In a further attempt to clarify the differences between their research and that of Perfetti et al. (1988) Brysbaert and Praet (1992) conducted a third experiment. Using the same experimental design, they manipulated the proportion of phonologically identical non-word masks. The results revealed that the phonologically identical non-word masks facilitated performance when a high proportion of these stimuli (77.8%) were included in the stimulus set. This effect was not observed when a low proportion of phonologically identical non-word masks (5.6%) was used. However, it is possible that in the low proportion homophonic condition the number of stimulus presentations were too few (10 trials) to observe a reliable effect of phonological influence. That is, the failure to observe facilitation for any one trial when a small proportion of homophonic stimuli are used has an enormous effect on the overall results in comparison to the rather inconsequential effect that a single trial would have when a high proportion of homophonic stimuli are used.

Lexical decision tasks have also been used to investigate phonological recoding in Arabic. Research conducted by Bentin and Ibrahim (1996) investigated phonological influences during word identification in Arabic. Arabic words may exist in written but not spoken Arabic, in spoken but not written Arabic or in both forms of Arabic. These differences were manipulated in stimulus conditions that were presented in Experiment 1. In their experiment high and low frequency words that existed only in both spoken and written Arabic were included with pseudowords (i.e., non-words) that were pronounceable but had no meaning in either spoken or written Arabic.

The subjects were required to indicate whether or not each of the letter strings was a real Arabic word. In general, the results of this experiment supported previous findings in other languages. That is, the reaction times associated with the high frequency words were significantly faster than those that were associated with the low frequency words and the pseudowords which did not differ from each other. In addition, the error rates for the stimulus conditions involved in the lexical decision task appeared not to differ from each other. Insofar as this finding was in general agreement with that of similar studies conducted in different languages the authors investigated the issue of phonological recoding in Arabic with a view to providing insight into the use of phonological codes during the word identification process.

In a subsequent study (Experiment 2) Bentin and Ibrahim investigated whether the phonological representations that were associated with words that existed only in spoken Arabic would influence the word identification process when phonetic transliterations were used. That is, the authors sought to determine whether the phonetic transliterations would hinder the subjects' ability to correctly reject the stimuli as being non-words. Three stimulus conditions were presented in this experiment. The stimuli were 1) words that exist only in written Arabic, 2) non-words that were phonetic transliterations of words that exist only in spoken Arabic and 3) pronounceable non-words that were meaningless in both spoken and written Arabic.

The subjects were required to decide whether the stimuli from these experimental conditions existed in the written form of Arabic. The results of the accuracy data showed that the errors were equally distributed across the stimulus conditions. However, the reaction time data suggested that the phonological representations of the letter strings influenced task performance. The reaction times that were associated with the words that exist in written Arabic were faster than those that were associated with the other two stimulus conditions. In contrast, the reaction times observed to non-words that were phonetic transliterations of spoken Arabic words were longer than those observed to the pronounceable non-words which differed phonologically from any real Arabic words. These differences in reaction time were interpreted as evidence suggesting that the phonological codes that were associated phonetic transliterations of spoken Arabic words influenced task performance.

However, the strength of this position is weakened by the inconsistency that was observed between that reaction time and accuracy data. Presumably, if the phonological codes that were associated with the phonetic transliterations of the spoken words interfered with task performance then this interference effect would also be reflected in the accuracy data. That is, these stimuli should be associated with a lower accuracy level insofar as the decision process is thought to be more difficult based on the longer latencies that were observed in this condition. Rather, the accuracy data suggests that the phonetic transliterations were treated in the same manner as the non-word stimuli which were phonologically different from written Arabic words. This similarity suggests that the phonological codes were not influential in the decision making process.

Further research using lexical decision tasks to investigate the role of phonology during word identification has involved a phenomenon known as priming. Priming occurs when a subject's task performance is facilitated by the prior exposure to related information. This facilitation in task performance is inferred from reduced response latencies and higher levels of accuracy that are observed to primed stimuli in comparison to those observed to unprimed stimuli (Richardson-Klavehn & Bjork, 1988; Neely, 1991). Several different forms of priming have been reported. One type of priming, referred to as phonological priming, occurs when task performance is facilitated by the prior presentation of phonologically related or identical stimuli.

Much of the research that has investigated the influence of phonology during visual word recognition has used phonological priming in isolated word paradigms. A recent study conducted by Ferrand and Grainger (1992) investigated the effects of phonology and orthography on visual word recognition in French. In their first study (Experiment 1), subjects performed a lexical decision task which required them to decide if the target stimuli (i.e., letter strings) were real words or non-words. The presentation of the target stimuli was briefly primed by the visual presentation of non-word stimuli.

Three types of non-word primes were manipulated. In comparison to the targets the primes were 1) orthographically similar and phonologically identical (pseudohomophones), 2) orthographically similar but phonologically different and 3) both orthographically and phonologically different. All of the primes were presented for 64 ms and were subjected to forward-masking. Forward-masking was used so that subjects would be unable to identify the primes that preceded the targets.

It was predicted that task performance would be facilitated by primes that were phonologically identical to the target stimuli. The reaction time data was interpreted as support for this prediction. The reaction times that were associated with the phonologically identical primes were significantly shorter than those that were associated with the two types of primes that were phonologically different from the targets. However, the reaction times that were associated with these phonologically different primes did not differ. Insofar as these differences in reaction time were not sensitive to whether the primes were orthographically similar to the targets these differences in reaction time were interpreted as evidence for phonological recoding.

Similarly, the error data was interpreted as evidence supporting the use of phonological codes during the lexical decision task. Primes that were phonologically identical to the targets were associated with significantly higher error rates than the other two types of primes that were phonologically different. These phonologically different primes were associated with error rates that did not differ from each other. This pattern of results was interpreted as evidence that phonological codes influenced the decision process required in the lexical decision task.

However, these results can also be interpreted as evidence of a speed-accuracy trade-off. That is, the pseudohomophone condition was associated with significantly shorter latencies and significantly higher error rates in comparison to the other two stimulus conditions. These results suggest that subjects made hasty decisions without being sure of their answers. Thus, it is difficult to determine the extent to which the subjects actually made lexical decisions versus responded to the phonological consistency between the primes and the targets.

Lexical decision tasks have provided evidence suggesting that phonological codes are used during word identification. However, this evidence has been contradictory inasmuch as the reaction time and accuracy data have frequently produced different patterns of performance across different studies as well as within the same study. Furthermore, phonological influences have been both eliminated and exaggerated with subtle changes in task requirements suggesting that phonological recoding may occur only under limited conditions. These inconsistencies have made it difficult to draw general conclusions with respect to the typical role of phonology in word identification processes.

In addition, an issue has been raised with regard to whether the evidence supporting phonological influences during the processes involved in making lexical decisions is indicative of whether these representations actually activate the semantic meaning that is associated with the words (Luo, 1996). One approach towards addressing this criticism has been to investigate the influence of phonological codes using an associative priming paradigm. Associative priming occurs when the subject's ability to respond to target stimuli is facilitated by the prior presentation of semantically related stimuli. Unlike the lexical decision tasks which require subjects to make decisions regarding the lexical status of a word string these paradigms require subjects to make decisions based upon the semantic meaning of the stimuli.

Lukatela and Turvey (1991) examined the influence of phonological codes during a naming task. In this research subjects were presented with a series of non-word stimuli that were primed by real English words. The non-word stimuli varied in terms of the degree to which they shared their phonological representations with real English words. There were four types of non-word stimuli. Half of the non-words were phonologically identical to (i.e., pseudohomophones) real English words that were either semantically related or unrelated to the primes that preceded them. The other half of the non-word stimuli rhymed with (non-pseudohomophones) real English words that were either semantically related or unrelated to the primes that preceded them. Insofar as the non-word stimuli were phonologically similar or identical to semantically related and unrelated words they were considered to be presented in associative and non-associative contexts, respectively.

The subjects were required to pronounce the non-word stimuli as quickly as possible following their presentation. It was hypothesized that subjects would be faster and more accurate in naming pseudohomophones when they were presented in an associative context than when they were presented in a non-associative context. In addition, pseudohomophones were expected to be named faster and more accurately than non-pseudohomophones regardless of the context in which they were presented. That is, the phonological representations that were associated with the pseudohomophones would facilitate task performance.

The results were consistent with the predictions for the study. The reaction time data showed that the pseudohomophones were named significantly faster than were the non-pseudohomophones. More specifically, pseudohomophones were named faster when they were presented in an associative context in comparison to a non-associative context. However, this effect was not observed for the non-pseudohomophones. Further, pseudohomophones that were presented in an associative context were named significantly faster than non-pseudohomophones that were also presented in a semantically related context.

The results of the accuracy data also supported the predictions of the study. The pseudohomophones were associated with significantly higher accuracy levels than were the non-pseudohomophones. In addition, the accuracy levels that were observed for pseudohomophones presented in an associative context were significantly higher than when pseudohomophones were presented in a non-associative context. In contrast, the accuracy levels that were associated with the non-pseudohomophones did not differ according to the context in which they were presented.

These findings were interpreted as evidence indicating that the phonological codes that were associated with the pseudohomophones facilitated performance on the naming task. The phonological codes activated the lexical representations that were associated with real English words. This activation was particularly facilitatory when the pseudohomophones were presented in an associative context. That is, when the pseudohomophones were associated with the primes that preceded them subjects were able to respond quicker and more accurately than when the primes were not associated. These findings were not attributable to the level of orthographic similarity that the non-word stimuli shared with the real English words (Experiment 2).

However, an alternative explanation for the results was proposed by the authors. They reasoned that their results may have been due to the high proportion of associatively related stimulus pairs that were included in the stimulus set. According to the authors the subjects may have attempted to generate semantically related words following the presentation of the primes. This strategy may have resulted in faster reaction times and higher accuracy levels for the associatively related stimulus pairs. This possibility was examined in a subsequent study.

In Experiment 3 Lukatela and Turvey (1991) investigated whether the facilitatory effect of phonological codes would be observed if the pseudohomophones were used as primes rather than as targets. The design of this experiment was similar to the earlier experiment insofar as the subjects named targets that were preceded by primes. In contrast to the earlier experiment, however, pseudohomophones and non-pseudohomophones were presented as primes for real English words and were presented in associative and non-associative contexts. In addition, the proportion of associatively related stimulus pairs was reduced in comparison to non-associatively related stimulus pairs (1:3 ratio). This reduction was used to discourage subjects from generating associatively related words following the presentation of the primes as a strategy to facilitate naming performance.

The results of this experiment were similar to those observed by Lukatela and Turvey (1991) in Experiment 2. The reaction time data showed that the pseudohomophones were named significantly faster in an associative context than in a non-associative context. This effect of associativeness was greater for pseudohomophones than for non-pseudohomophones which did not benefit significantly from being presented in an associative context. In contrast to the reaction time data, the accuracy data did not reveal significant differences in the accuracy with which targets that were primed by pseudohomophones and non-pseudohomophones were named.

The reaction time data do provide support for the position that the phonological codes associated with pseudohomophones primed naming performance for real word targets. However, the accuracy data were inconclusive insofar as the pseudohomophone primes did not facilitate performance in comparison to the non-pseudohomophones. These somewhat contradictory findings make it difficult to understand whether pseudohomophone primes activate lexical representations as efficiently as real word primes did in Experiment 2. In an effort to answer this question the authors compared the reaction time data for associatively related stimulus pairs in which the target words were primed by either real words (BOY-GIRL) or pseudohomophones (TAYBLE-CHAIR). The results of this analysis revealed that the naming latencies that were associated with these two types of primes were not different.

Overall, these results were interpreted as evidence indicating that phonological codes influence performance on a naming task. This effect was not due to the proportion of associatively related stimulus pairs that were included in the stimulus set inasmuch as evidence for phonological recoding was observed in both Experiments 1 and 3 which manipulated this factor. This result stands in contrast to the findings reported by Brysbaert and Praet (1992) that the effect of phonological recoding during a word identification task was observed only when a high proportion of homophonic stimuli were included in the stimulus set.

The reason for these differences is not clear however, it is possible that they are due to differences in task requirements. Although both tasks involved identifying words, Brysbaert and Praet (1992) used non-word masks that were homophonic with real words whereas, Lukatela and Turvey (1991) primed the targets with non-words that were homophonic with real words. It is possible that the extent to which phonological codes facilitated performance in a naming task was affected by factors such as the use of non-word masks and whether the pseudohomophones were presented before or after the target words. Despite these differences the overall findings from these studies provide evidence indicating that phonological codes facilitate task performance.

More recently, research conducted by Luo (1996) investigated phonological recoding using a word pair task. In this task, a series of word-pairs were presented to the subjects. Following the presentation of each word-pair a third word was presented. The subjects were required to decide which of the two words in the previously presented word-pair was semantically related to the third word. Thus, the decisions were based on the semantic relationship that existed between the third word and one of the words in the word-pair.

Each word-pair consisted of a word that was semantically related (LION) to the third word (WOLF) and a distracter word that was semantically unrelated to the third word. There were two types of distracter words. The distracters were either 1) phonologically identical to a word that was semantically related to the third word (BARE was presented and is phonologically identical to the word BEAR) or 2) phonologically different from any words that were semantically related to the third word (BEAN). These two types of distracters (homophone foils and visual controls, respectively) were approximately equated in terms of word frequency and letter length.

It was predicted that the phonological codes that were associated with the homophone foils would interfere with task performance more than the visual controls. That is, subjects would erroneously accept homophone foils as being semantically related to the third word more frequently than they would erroneously accept visual controls. The results of the experiment supported this prediction insofar as decisions involving homophone foils were significantly less accurate and had significantly longer latencies than the decisions involving the visual controls. These findings were interpreted as evidence supporting the position that phonological codes can gain access to the mental lexicon and thereby influence the word identification process.

Similar results were reported by Van Orden (1987) using a semantic categorization task. In this task, subjects were presented with a series of semantic categories. The presentation of each category name (A FLOWER) was followed by the presentation of either a semantically appropriate exemplar (TULIP) or a semantically inappropriate word. There were two types of semantically inappropriate words. Inappropriate words were either 1) phonologically identical to a semantically appropriate word (ROWS is phonologically identical to its homophone partner ROSE) or 2) phonologically different from an appropriate category exemplar (ROBS).

The two types of semantically inappropriate exemplars (homophone foils and visual controls, respectively) were considered to be orthographically similar to each other. However, these stimuli were either orthographically similar or dissimilar to the appropriate category exemplars. Orthographic similarity was calculated using a formula that produced scores ranging from 0 to 1 where 1 is an identical match. This calculation was based upon factors such as the number of letters in common, letter length and letter position. Orthographically similar and dissimilar foils and visual controls had means of .74 and .46, respectively.

The subjects were required to decide whether or not the word which followed the presentation of the semantic category was an appropriate category exemplar. It was predicted that the phonological codes that were associated with the homophone foils would interfere with the task performance. That is, subjects were expected to erroneously accept the homophone foils more frequently than the visual controls as appropriate category exemplars. The effect of interference was predicted to be greater for homophone foils that were orthographically similar to their homophone partner.

The results of the study supported these hypotheses. The accuracy level that was associated with the homophone foils was significantly lower than that which was associated with the visual controls. In addition, homophone foils that were orthographically similar to their homophone partner were associated with significantly lower levels of accuracy than foils that were orthographically dissimilar to their partner. This effect was not reported for the orthographically similar and dissimilar visual controls. These findings were interpreted as evidence that phonological codes influenced performance during the semantic categorization tasks. Inasmuch as the decisions were based upon the semantic relationship between the categories and the exemplars these results indicated that phonological codes associated with the homophone foils accessed the semantically appropriate lexical representations.

However, the results also indicated that the level of orthographic similarity that exists between the semantically inappropriate homophone foils and the appropriate exemplars influenced the accuracy level during the task. A subsequent experiment (Experiment 2) examined this issue more closely using pattern masks. In this experiment a pattern mask followed the presentation of the possible exemplars so as to disrupt the visual representation of the words.

Presumably, subjects were forced to rely on the phonological representations of the words to make their decisions.

It was predicted that the phonological codes that were associated with the homophone foils would produce lower levels of accuracy than the visual controls. However, the previously observed effect of orthographic similarity between the homophone foils and their partners was not expected to be observed. The results of the study supported these predictions as lower levels of accuracy were associated with the homophone foils than with the visual controls. However, the accuracy levels that were associated with the homophone foils did not differ according to whether they were orthographically similar or dissimilar to their homophone partner. This effect was not reported for the visual controls. These findings were interpreted as evidence supporting the role of phonology during the word identification process.

Once again, an alternative explanation can also account for these findings. Inasmuch as Van Orden (1987) failed to report reaction time data it is possible that the evidence for phonological recoding may be due to a speed-accuracy trade-off. While this possibility exists it appears to be unlikely insofar as Van Orden, Johnston and Hale (1988) reported similar findings using the same experimental design as was used by Van Orden (1987) which did include reaction time. Van Orden et al. (1988) included both homophone foils and non-word homophones (SUTE) as possible exemplars in their experiment. The accuracy levels that were associated with these two types of stimuli did not differ from each other but were significantly lower than the accuracy levels associated with visual control words and non-words. In contrast, the reaction times that were associated with erroneously accepting the homophone foils and non-word homophones as appropriate category exemplars did not differ from those associated with the correct acceptance of the appropriate exemplars. This pattern of performance is not consistent with that of a speed-accuracy trade-off. However, the reaction time data does not suggest that phonological codes associated with the phonologically ambiguous stimuli interfered with task performance. That is, evidence of phonological recoding would be inferred from longer reaction times that were observed to homophone foils and non-word homophones in comparison to the visual controls. Thus, these findings provide somewhat contradictory evidence with regard to the use of phonological codes during semantic categorization task.

More recently Coltheart et al. (1994) used a semantic categorization task to investigate some factors that may influence the extent to which phonological codes influence performance during a semantic categorization task. The results of the error data analysis replicated findings reported by both Van Orden (1987) and Van Orden et al. (1988). In Experiments 1 and 2 Coltheart et al. (1994) reported that higher error rates were associated with homophone foils and non-word homophones than with visual controls. Further, the error rates associated with homophone foils and non-word homophones did not differ from each other.

The results of the reaction time data provided further support for the role of phonology during word identification. That is, the decisions associated with homophone foils and non-word homophones were significantly longer in latency than those associated with visual controls but were not different from each other. These findings suggest that the phonological codes associated with the homophonic stimuli interfered with task performance regardless of whether the stimuli were words or non-words. Insofar as the task required subjects to make decisions regarding the semantic meaning of the stimuli the higher error rate observed in the homophonic condition suggests that the phonological codes that were associated with these words were able to access the lexicon.

In contrast to the lexical decision tasks, and naming tasks, these semantic categorization tasks require subjects to base their decisions upon whether a semantic relationship exists between stimuli. Presumably, these decisions require that the lexical representations that are associated with the target stimuli are activated. The evidence gathered from these tasks supports the position that phonological codes may be used to access these lexical representations. This activation can, depending upon the nature of the experimental task, facilitate or interfere with task performance. Thus, the semantic categorization tasks provide strong support for the position that phonological codes influence processes involved in word identification.

However, semantic categorization tasks do provide a somewhat limited view of the role of phonology during these processes. As in the case of the lexical decision and naming tasks, semantic categorization tasks are concerned with the role of phonology during the identification of isolated words. That is, these experimental tasks have provided evidence supporting the position that phonological codes influence word identification processes in isolated words. However, the assumption that phonological codes assume a similar role during the reading of text does not necessarily follow.

It is possible that the extent to which subjects rely on phonological codes while reading text differs from that observed in paradigms that involve isolated words or word-pairs (Davidson, 1986). This possibility seems plausible insofar as the evidence supporting the use of phonological codes in the identification of isolated words has yielded conflicting evidence. Consequently, researchers have been cautious about making generalizations from the evidence supporting phonological recoding that was obtained from isolated word paradigms. However, some efforts have been made to attack directly the issue of phonological recoding during the silent reading of text.

A recent study conducted by Coltheart et al. (1991) investigated the issue of phonological recoding during silent reading of sentences. In their study subjects were presented with a series of visually presented sentences. Each of the sentences was presented in its entirety in the middle of a computer screen. The subjects were required to judge the semantic acceptability of the sentences.

Equal proportions of the sentences were semantically appropriate and inappropriate. The spelling-to-sound regularity of the semantically inappropriate stimuli was manipulated in the study. Three types of semantically incongruous stimuli which shared their phonological representations with the contextually appropriate words (homophonic) for the sentences were presented. These stimuli were either 1) regularly spelled words, 2) irregularly spelled words and 3) non-word stimuli. Regular words had consistent spelling-to-sound letter patterns whereas, the irregular words did not. Therefore, the word identification processes could occur through a direct mapping of orthographic representations to phonological representations as depicted by the non-lexical route in the dual-route model. In contrast, the identification of the irregular words could only be achieved through the lexical route since the orthographic representations do not map directly onto the phonological representations.

In addition, semantically inappropriate stimuli were manipulated which did not share their phonological representations with the contextually appropriate words (visual control). These visual control stimuli were either regularly or irregularly spelled words or they were non-words. The homophonic and visual control stimuli were equated for orthographic similarity to each other and to the contextually appropriate words for the sentences using a rating system similar to that used by Van Orden (1987).

Coltheart et al. (1991) predicted that the phonological codes that were associated with the homophonic words and non-words would interfere with performance on the sentence reading task. The results of the experiment supported this prediction. Overall, semantically inappropriate sentences containing stimuli that were phonologically appropriate were associated with significantly higher error rates than those that contained visual controls. In addition, homophones that were regularly spelled had significantly higher error rates than did irregularly spelled homophones which had significantly higher error rates than non-word homophones. However, a significant interaction revealed that error rates associated with non-word homophones did not differ from those associated with non-word visual controls.

These findings were interpreted as evidence for phonological recoding during reading of visually presented sentences. However, the results of the reaction time data suggest that an alternative explanation may account for the results. That is, the sentences that were associated with homophonic stimuli had significantly shorter latencies than sentences that were associated with visual controls. These results suggest that the evidence supporting phonological recoding may be due to a speed-accuracy trade-off. This explanation seems plausible insofar as a high proportion of homophonic stimuli (25%) were presented during the experiment. Thus, the reaction time data and error data provide contradictory evidence with regard to the use of phonological codes during reading. Similar contradictions in behavioural data were reported by Baron (1973) who investigated phonological recoding during the reading of phrases.

In a related study Daneman and Stainton (1991) examined the influence of phonology during a proofreading task. Subjects were required to read a written passage that contained 1500 words. Their task was to identify as many semantic errors as they could find while they read the passage. There were two types of semantic errors. Semantically inappropriate sentences were either 1) phonologically identical to the contextually appropriate sentence words (homophone foil) or 2) phonologically different from the contextually appropriate sentence words (visual controls). These semantically incongruous stimuli were equated with each other and with the contextually appropriate sentence words in terms of their orthographic similarity. Orthographically similar words satisfied several criteria such as the number of shared letters, initial letters and letter length of the words.

It was predicted that the phonological codes that were associated with the homophone foils would interfere with the subjects' ability to identify these words as semantically inappropriate. The results of the study supported this prediction and showed that homophone foils were associated with significantly higher error rates than were the visual controls. That is, subjects were more likely to accept homophone foils as being semantically appropriate than they were to accept the visual controls. Inasmuch as these stimuli (homophone foils and visual controls) were both semantically inappropriate and orthographically similar to the contextually appropriate words these findings were interpreted as evidence supporting the position that phonological codes influenced performance during reading.

However, this pattern of performance was only observed when subjects had been familiarized with the text prior to engaging in the proofreading task. This finding suggests that phonological codes influenced task performance when subjects were able to generate expectations for the text they were required to proofread. It is possible that these expectations made it more difficult for subjects to identify semantically inappropriate words. That is, the phonological codes associated with the homophone foils may activate the contextually appropriate lexical representations. The activation of the appropriate lexical representation may make it more difficult to reject homophone foils as being semantically inappropriate.

This position is supported by subsequent research (Experiment 4) conducted by Daneman and Stainton (1991). This experiment used the same design as the previous study. In addition, to being asked to identify semantic errors subjects were asked to provide the semantically appropriate words for the passage. The results of this task showed that subjects were able to provide semantically appropriate homophones more often than they were able to provide the semantically appropriate non-homophonic words. This finding suggests that the phonological codes associated with homophone foils activated the semantically appropriate lexical representations which increased the likelihood of providing the semantically correct words for the passage. Additional evidence indicating that phonological codes influence visual word recognition during the reading of sentences has been reported by other researchers (e.g., Waters et al., 1992; Coltheart, Avons & Trollope, 1990; Davidson, 1986; Coltheart, Laxon, Rickard & Elton, 1988; Baron, 1973; Treiman, Freyd & Baron, 1983).

Overall, behavioural paradigms such as those previously described provide evidence to suggest that phonological codes influence task performance. However, the extent to which phonological codes are used during these tasks can be affected by manipulations of task requirements and variations in stimulus sets. Further, in many cases the reaction time data and error data provide contradictory evidence with respect to how phonological codes influence task performance. Consequently, researchers have begun to examine the role of phonology during word identification using more objective measures of performance.

Eye movement recordings

Another behavioural technique that has been used to examine language processing involves eye movement recordings (e.g., Altarriba, Kroll, Sholl & Rayner, 1996; Rayner & Raney, 1996; Rayner, Sereno & Raney, 1996). Eye movements are recorded while subjects are engaged in a reading task. The eye movement patterns that are observed during reading are used to make inferences about the processes involved in word identification (Rayner, Sereno, Lesch & Pollatsek, 1995). That is, research has demonstrated that the frequency and duration of the eye movements that are made during reading are influenced by the processes that are involved in word identification (Rayner, 1978).

Recent research has used this technique to investigate the role of phonology during the reading. Daneman and Reingold (1993) recorded the eye movements that subjects made while they were reading the same passage of written text used by Daneman and Stainton (1991) in which some of the sentences in the passage contained semantic incongruities words and some did not. As described previously the incongruous words in the passage were either phonologically identical to (i.e., homophone foils) or phonologically different from (i.e., visual controls) the contextually appropriate words for the sentences. As in the study conducted by Daneman and Stainton (1991) these semantically inappropriate words were orthographically similar to each other and the contextually appropriate words for the sentences. Subjects were required to read the passage and a behavioural task was not used.

Daneman and Reingold (1993) predicted that the phonological codes that were associated with the homophone foils would influence the word identification process. The results of the study supported this prediction and showed that the homophone foils were associated with a unique pattern of eye movements in comparison to the other two stimulus conditions. The initial fixation of the semantically inappropriate homophone foils and visual controls did not differ from each other but were both significantly longer than the initial fixation time associated with semantically congruous words. The authors interpreted this finding as evidence indicating that the phonological codes associated with the homophone foils did not interfere with the reading task more than the visual controls. That is, this finding suggested that phonological codes did not influence the processes involved in word recognition.

Further examination of the eye movement data by Daneman and Reingold (1993) showed that these stimulus conditions differed in terms of the total amount of processing time spent on the stimuli. The stimuli in both incongruous conditions were fixated multiple times and the total amount of time that the visual controls were fixated was significantly longer than that observed in the case of the homophone foils. These findings were interpreted by the authors as evidence supporting the position that phonological codes influenced the language processes that take place after word identification. According to the authors the processes that occur after word identification involve activating the semantically appropriate word for the sentence.

The phonological codes that were associated with the homophone foils facilitated the identification of the semantically appropriate words and resulted in a shorter amount of overall processing time. Evidence of this facilitatory effect was inferred from the shorter overall processing times that were observed to the homophone foils. This result is in line with that reported by Daneman and Stainton (1991) in their earlier study indicating that subjects were able to generate the semantically appropriate homophones more often than they were able to generate the semantically appropriate non-homophonic words. Thus, the findings reported by Daneman and Reingold (1993) suggest that phonological codes are influential after word identification has occurred.

Another study conducted by Inhoff and Topolski (1994) investigated the issue of phonological recoding during reading. In their study, subjects were required to read passages of text while their eye movements were recorded. Three types of semantic errors were manipulated in this study. Incongruous stimuli were orthographically similar words (i.e., visual controls) and non-words (i.e., pseudowords) or they were non-words that were phonologically identical to real words (i.e., pseudohomophones). Once the subjects had read the passages they were required to decide whether each of the passages was coherent.

It was predicted that the phonological codes that were associated with the pseudohomophones would interfere with task performance making it more difficult to identify the passages as incoherent. In addition, the pattern of eye movements that was associated with the pseudohomophones was predicted to differ from the patterns associated with the other incongruous stimulus conditions (visual controls and pseudowords). In contrast to Daneman and Reingold (1993), the results indicated that phonological recoding occurred during silent reading. The pseudohomophones were associated with significantly higher error rates (i.e., were less frequently detected) than were the pseudowords. A significant difference in error rates between these stimulus conditions and the visual control condition was not reported.

Further evidence of phonological recoding was obtained from the eye movement data. The initial fixation of the pseudohomophones was significantly shorter in duration than that associated with the pseudowords. The total amount of processing time that was associated with the pseudohomophones was significantly shorter than that associated with the pseudowords. A significant difference in the fixation durations between these stimulus conditions and the visual control condition was not reported.

These eye movement results were interpreted as evidence indicating that the pseudohomophones had a greater interference effect than did the pseudoword stimuli. However, it is difficult to ascertain whether the effect of interference that was associated with pseudohomophones was larger than that associated with the visual controls inasmuch as the authors did not report whether differences between these stimuli (pseudohomophones and pseudowords) and visual controls were observed. Consequently, the results reported by Inhoff and Topolski are limited in terms of the extent to which they provide support for phonological recoding during silent reading of passages.

Inhoff and Topolski's observation that the initial fixation of the pseudohomophones was significantly shorter in duration than that associated with the pseudowords is in contrast with Daneman and Reingold (1993) who did not observe differences between the homophone foils and visual control stimulus conditions. While there is no clear explanation for this difference between these experiments, it is possible that the differences in tasks requirements are responsible. For example, semantically incongruous words were used by Daneman and Reingold whereas, Inhoff and Topolski presented non-words as the incongruous stimuli in their study. In addition, Daneman and Reingold asked subjects to simply read the passages of text whereas Inhoff and Topolski required subjects to decide whether the passages of text they read were coherent. The inclusion of this semantic judgement task and the use of non-word stimuli may have altered the strategy used by the subjects during reading in order to optimize their behavioural performance. This possibility clearly requires further investigation however, recent research has suggested that shifts in processing strategies during visual word recognition can occur (Stone & Van Orden, 1993; Lupker, Brown & Columbo, 1997).

Further research using eye movements to investigate the influence of phonological processes involved in word identification has been recently conducted by Rayner, Pollatsek and Binder (1997). The aim of this research was to resolve conflicts concerning the use of phonological codes generated in earlier research. Rayner et al.'s (1997) first experiment was similar to previously described studies which required subjects to read short passages of text containing semantic errors that were phonologically identical (i.e., homophonic) to the contextually appropriate words. The goal of this experiment was to determine whether the pattern of eye movements recorded to semantically congruous homophones differed from the eye movements recorded to semantically incongruous homophone foils.

There were four types of semantically incongruous stimuli. Incongruous stimuli consisted of homophone foils or pseudohomophones. The homophone foils were either orthographically similar or dissimilar to their homophone partners. Homophone foils that were orthographically similar to their homophone partner shared either 1) the first letter or 2) the first two letters with their partners. Orthographically dissimilar homophone foils did not share either of the first two letters of the word. Finally, pseudohomophones were phonologically identical (e.g., brane) to a non-homophonic word (i.e., brain). All pseudohomophones were orthographically similar (i.e., shared the first two letters) to the non-homophonic word and shared the first two letters with this word.

The context provided in the passages made one member of a homophone pair highly predictable. Eye movements were recorded while the subjects read the text. Subjects were not required to perform a behavioural task while they were reading the passages. However, the presentation of the text passages was stopped periodically (on about one-third of the trials) and subjects were asked to answer comprehension questions about the passages.

Rayner et al. (1997) predicted that the eye movement recordings associated with the congruous homophones would not differ from those associated with the incongruous homophone foils if phonological codes influenced the word identification process. The results of the study did not support this prediction inasmuch as the incongruous homophones were associated with significantly longer first fixations and total fixation durations than were the congruous homophones. Further investigation of the data revealed that the semantically incongruous homophone foils did not differ from the congruous homophones in terms of first fixation latency when these words were orthographically similar to each other (i.e., shared the first two letters). The absence of a difference in first fixation latency between these stimulus conditions could be interpreted as evidence suggesting that phonological codes associated with the homophone foils influenced the word identification process. However, as the authors pointed out this finding could also be interpreted as evidence indicating that subjects did not notice the presence of the incongruous homophone foils because they were orthographically similar to their homophone partners.

Rayner et al. (1997) conducted a subsequent experiment to determine whether the congruous and incongruous homophones elicited similar eye movement patterns because phonological recoding occurred or because these stimuli were orthographically similar to each other. In a second experiment, subjects were required to read passages of text containing semantic errors. The semantic errors were words that were either phonologically identical to (homophone foils) or phonologically different from (spelling controls) the homophones that were contextually appropriate for the passage. Pseudohomophones were not included in this experiment. The orthographic similarity of the semantically incongruous stimuli was manipulated as in the previous experiment.

It was predicted that if phonological codes influenced the word identification processes then the pattern of eye movements recorded to the phonologically expected homophone foils would differ from that recorded to the phonologically unexpected spelling controls. The results of the experiment supported this prediction. The congruous homophones and incongruous homophone foils did not differ in first fixation latency when these stimuli were orthographically similar to each other. However, the incongruous homophone foils were associated with significantly longer first fixation latencies than the congruous homophones when they were orthographically dissimilar from their homophone partners. These findings confirmed the results reported in their first experiment. In addition, the results of Experiment 2 provided support for phonological recoding inasmuch as the first fixation latency associated with the orthographically similar spelling control words were significantly longer than the latencies associated with either the congruous homophones or the incongruous homophone foils.

Thus, the findings reported by Rayner et al. (1997) provide strong support for the position that phonological codes are influential in the word identification process. This conclusion is, on the surface, in contrast with Daneman and Reingold (1993) who reported that phonological codes are used after word identification has been accomplished. However, according to Rayner et al. (1997) the difference between these conclusions is most likely due to the use of different data sets to address the issue of phonological recoding during reading. Rayner et al. (1997) compared the data associated with the initial fixations of the stimuli since the first fixation duration is indicative of the early processes involved in word identification (Inhoff, 1984; Rayner & Pollatsek, 1987; Rayner, Sereno, Morris, Schmauder & Clifton, 1989). In contrast, Daneman and Reingold (1993) primarily reported differences between stimulus conditions based upon the total amount of time spent processing the stimuli. Inasmuch as the first fixation data represent the processes that occur *during* word identification whereas, the data associated with total processing time represent the processes that occur both *during* and *after* word identification these data sets reflect different cognitive processes and, not surprisingly, led to different conclusions regarding the use of phonological codes during word identification.

Despite the conflicting conclusions regarding the use of phonological codes during the word identification process both Rayner et al. (1997) and Daneman and Reingold (1993) agree that phonological codes are used after word identification has been accomplished. As mentioned earlier, Daneman and Reingold reported that the homophone foils were associated with shorter overall processing latencies than were the visual controls. This finding was interpreted as evidence that the phonological codes associated with the homophone foils facilitated the lexical activation of the semantically appropriate words after word identification and resulted in shorter overall processing latencies. The difference in total processing time that was observed between the homophone foils and the spelling controls was also reported by Rayner et al. (1997).

Thus, the initial fixation latency data obtained from eye movement studies suggests that phonological codes influence the processes involved in silent reading. However, these studies are also subject to criticisms which suggest that phonological recoding may occur only under certain experimental conditions such as being familiar with the text. In addition, the effect of including non-word visual controls in the passages of text remains unclear insofar as these effects were not reported by Inhoff and Topolski (1994). While it is conceivable that phonological codes assume an important role during silent reading the magnitude of this effect appears to be affected by certain task requirements.

The influence of phonological codes has been investigated using a variety of behavioural tasks. Overall, these behavioural techniques have provided evidence suggesting that phonological recoding occurs during word identification. However, these techniques are limited in the type of information they can provide. While it is possible to make inferences about the cognitive processes that are responsible for the differences observed between response latencies, accuracy levels or frequency and duration of eye movements these techniques are limited in terms of their ability to provide insight into the on-line processing of language.

The reason behavioural tasks do not provide insight into the on-line processing of language is that the data gathered from these paradigms typically represents the completion of several processes rather than that of any single process. These processes may be cognitive or even motoric in nature (Kramer & Donchin, 1987). In order to understand the influence of a particular process that is involved in language it is important that it be examined independently from other cognitive processes.

Chapter Two

ERPs and the study of language processes

Inherent limitations in behavioural paradigms have led at least one critic to the conclusion that: "Ideally, what is required is an on-line and continuous measure, one that taps into the state of affairs in the lexical processing system while it operates in real time" (Zwitserlood, 1989, p. 29; see also, Swinney, 1981). The central position of this thesis is that event-related brain potentials (ERPs) provide precisely the required continuous on-line measure to investigate the subtle processes involved in language. ERPs provide a continuous, information-rich, real-time analysis of the processes that are involved in responding to linguistic stimuli because they are sensitive to changes in neural activity that occur while a cognitive task is being performed (Kutas & Van Petten, 1988; Kounios, 1996). Further, cognitive manipulations can be objectively measured using ERP technology.

ERP responses to language stimuli are referred to as signals. These signals are embedded within spontaneous neural activity, referred to as noise, that is recorded by electroencephalography (EEG) (Cooper, Osselton, & Shaw, 1980). Although the relationship between the ERP components and the neural processes is not well understood it is clear that neural activity can be recorded reliably in response to stimuli (Allison, Wood & McCarthy, 1986). The particular component that is elicited is determined by the nature of the stimulus that is presented.

The neural activity that is recorded by an EEG is believed to originate from the post-synaptic dendritic branches of pyramidal cells located within the cortex. These cells represent approximately 70 percent of the cortical neurons and are named after the unique pyramidal shape of their cell body. Pyramidal cells range widely in size and interact with other cortical neurons as well as with various subcortical neurons (Nolte, 1988). These neurons produce a synchronized current in response to stimuli. This current is of sufficient magnitude to be recorded reliably on the scalp and is referred to as the ERP response (Nunez, 1981).

In order to obtain a reliable ERP signal the stimulus that elicits a particular ERP component is presented repeatedly. The EEG recordings that are obtained from the various stimulus presentations are then averaged together to enhance the ERP signal. That is, the averaging process enhances the ERP signal by averaging out much of the noise that is present on individual presentations. This process generates a relatively clear neural signal of brain activity that is associated with the stimulus (Cooper et al., 1980).

The presentation of certain types of stimuli results in the elicitation of particular ERP signals that are referred to as components (Regan, 1989). ERP components that are consistently elicited in response to the specific stimulus presentation are held to be "time-locked" to that stimulus. That is, these components typically occur within a certain latency period and are associated with a particular experimental variable or set of experimental variables (Donchin, Ritter, & McCallum, 1978). ERP components do not simply refer to the presence of a distinct peak within a certain latency period of the waveform. Rather, peaks observed in the waveforms are considered to reflect ERP components only when their sensitivity to experimental manipulations can be demonstrated reliably. Thus, each ERP component has been demonstrated to occur reliably to a specific type of experimental manipulation.

Historically, ERP components have been classified as falling into one of three categories. This classification is based upon aspects of the stimulus to which the component is sensitive. What are termed exogenous components typically occur within 200 ms of the stimulus presentation and have either a positive or a negative polarity. These components are sensitive to such physical characteristics of the stimuli as intensity, modality and rate of presentation (Kramer & Donchin, 1987). Exogenous components are normally evident regardless of whether subjects actively attend to the stimuli (Nätäänen, 1990).

In contrast, endogenous components, which can also be positive or negative in polarity, are associated with longer latencies. The elicitation of endogenous components is influenced by the processing demands of the task and requires subjects to attend to the stimuli (Kramer & Donchin, 1987). Endogenous components have been demonstrated to be sensitive to deviations in expectancy that are based upon some aspect of cognitive processing. Each of these components is unique in terms of its topographical distribution, polarity and the conditions under which it is elicited (Rugg & Nagy, 1987). Finally, a third type of ERP component, referred to as mesogenous components, has been identified. These components are proposed to reflect both exogenous and endogenous processing (Begleiter, Porjesz, Yerre & Kissin, 1973).

ERP components: The P300 component and the discovery of the N400 component

There has been growing interest in the use of(ERPs) to study cognitive processes in general, and language mechanisms in particular (Fischler & Raney, 1991; Kramer & Donchin, 1987). One approach to studying ERPs has been to relate predictable and systematic changes in a particular component to specific aspects of a cognitive process. Variations in ERP patterns are related to expectancies held by the subject (Kutas & Hillyard, 1980a). Insofar as subjects have been shown to generate expectancies during cognitive tasks (Ratcliff & McKoon, 1989) ERP components can be used to study the expectancies generated during language processing.

Researchers have sought to determine the processes underlying a component referred to as the P300 by using different types of experimental manipulations. This centro-parietally distributed component has been observed in the visual and auditory modality and occurs approximately 300 ms to 1000 ms following the stimulus presentation. The latency of the P300 is influenced by the complexity of the task (Donchin, 1981). In addition, the P300 is sensitive to variations in the probability of the stimuli (Simson, Vaughan, Jr., & Ritter, 1977; Johnson, 1986). For example, stimuli that are rare or unexpected elicit a P300 response particularly when they are attended (Squires, Wickens, Squires, & Donchin, 1981). Evidence indicating that the P300 is sensitive to unexpected events in a stimulus set has led researchers to hypothesize that it may also be sensitive to deviations in language.

Kutas and Hillyard (1980a) investigated the role of contextual constraint during a sentence reading task. The terminal words for one quarter of the sentences were inconsistent with the semantic expectations that were generated by the sentence context. The degree to which certain terminal words could be expected to complete the sentences was further manipulated by varying the level of contextual constraint within the sentences. As the sentence context became more and more informative the number of words that could be used as a semantically appropriate terminal word for a sentence diminished (Shannon, 1948). A terminal word required to complete a highly contextually constrained sentence is held to have a high "cloze" probability because it is used more frequently than any other word. A word that would be very infrequently used to complete a highly contextually constrained sentence would be held to have low cloze probability because of the rarity by which it would be selected (Taylor, 1953).

Kutas and Hillyard (1980a) manipulated the semantic appropriateness of the terminal words for the sentences. The unexpected terminal words presented in Experiments 1 and 2 of their study were, in varying degrees, semantically incongruous to the sentence context. In Experiment 1, the terminal words deviated moderately from the expected terminal words (e.g., "He took a sip from the waterfall.") whereas, in Experiment 2 the terminal words deviated strongly (e.g., "He took a sip from the transmitter.") from the anticipated final words.

In a third experiment, all sentences were completed in a congruous manner by using high cloze probability words. However, one quarter of the terminal words used to complete the sentences were presented using a larger font size than that used for the preceding words in the sentence. Thus, Experiments 1 and 2 manipulated the degree to which the terminal words of the sentences deviated from the semantic meaning of the high cloze probability words whereas, the third experiment manipulated the physical features of the terminal words. ERPs were recorded to the deviations used in each of the three experiments.

The results of the three experiments indicated that terminal words that deviated from the semantic meaning of the high cloze probability words produced different ERP responses than did those that were elicited by physically deviant words. The semantically incongruous terminal words in both Experiments 1 and 2 failed to elicit a P300 response regardless of the degree to which they deviated from the anticipated terminal words. In contrast, a P300 response was elicited in Experiment 3 by the terminal words that had been presented in a larger font size than the preceding words in the sentence. These results indicated that the P300 response was sensitive to deviations in expectancy that involved the physical characteristics of the terminal words but that it was not sensitive to deviations in the semantic expectancy for these words.

However, another component did appear to be sensitive to deviations in semantic expectancy. A component with negative polarity, that has subsequently become known as the N400 response, was elicited by semantically incongruous terminal words that deviated semantically, but not physically, from the high cloze probability words. Further, the amplitude of the N400 response was influenced by the degree to which the terminal words deviated from the expected sentence-ending words. Terminal words that deviated strongly from the anticipated words produced larger N400 responses than did those that deviated only moderately. In contrast, a N400 response was not elicited by anticipated, semantically appropriate words. These findings suggest that the amplitude of the N400 response was determined by the extent to which the terminal words deviated from the high cloze probability words that were expected to complete the sentences.

Overall, the results obtained from Kutas and Hillyard's (1980a) experiments indicate that while the P300 and N400 components are elicited by unexpected stimuli the type of deviation which is responsible for eliciting each of these components is different. The N400 is associated with deviations in expectancies within a set of established symbols that are supported by long-term memory stores. For example, the N400 response has been observed to words (Kutas & Hillyard, 1980a & b; Kutas & Van Petten, 1988; Stelmack & Miles, 1990) and pictures (Ganis, Kutas & Sereno, 1996; Noldy, Stelmack & Campbell, 1990; Holcomb & McPherson, 1994; Nigam, Hoffman & Simons, 1992) that violate the expectancy for particular stimuli generated by a preceding context.

In contrast, the P300 is elicited by deviations in the physical characteristics of stimuli. These shorter term expectancies can be generated by the manipulation that is used within an experimental task rather than by expectancies anchored in long-term memory. For example, an unexpected presentation of a low frequency tone in a series of high frequency tones would be sufficient to elicit a P300 response (Simson et al. 1977). Such unexpectancies are based upon the experimental content rather than upon any previously stored long-term memories (Kutas & Van Petten, 1988). Recent research indicates that the N400 appears to be tied to semantic processing rather than grammatical (Kutas & Hillyard, 1983) or syntactic processing (Van Petten & Kutas, 1991; Friederici, Pfiefer, & Hahne, 1993; Rosler, Putz, Friederici, & Hahne, 1993; Mundt, Heinz, & Mangun, 1993). Thus, the factors that are responsible for eliciting the N400 and P300 components are different. These differences have led researchers to conclude that the processes underlying these components are separate and distinct.

Linguistic priming and the N400 component

The N400 component is extremely robust in that it is elicited in both the visual (e.g., Kutas & Hillyard, 1980a, b & c; Van Petten, 1993; see Kutas & Van Petten, 1988 for a review) and auditory (e.g., Connolly, Stewart, & Phillips, 1990; Connolly, Phillips, Stewart, & Brake, 1992; Holcomb & Neville, 1991; O'Halloran, Isenhart, Sandman, & Larkey, 1988) modalities. Research indicates that the N400 response is typically maximized over centro-parietal brain areas (Kutas & Van Petten, 1988). However, the N400 component has also been observed to be enhanced over frontal brain areas as well as equally distributed across the midline sites (Pritchard, Shappell & Brandt, 1991). Further, the N400 responses are generally observed to be lateralized over the left hemisphere but have been reported to be slightly lateralized over the right hemisphere or laterally symmetrical (Pritchard et al., 1991). While there is no clear explanation for these topographical differences it seems reasonable to propose that they are associated with differences in task requirements (Connolly, Phillips & Forbes 1995).

Following discovery of the N400, much research has focused on providing a more precise specification of the language processes that are responsible for eliciting it (e.g., Paller, Kutas & Mayes, 1987; Neville, Kutas, Chesney & Schmidt, 1987; Fischler, Bloom, Childers, Roucos & Perry, 1983; Fischler, Bloom, Childers, Arroya & Perry, 1984). This research effort has largely been focused on priming. As described earlier, priming refers to the facilitation in task performance that results from the prior exposure to semantically related or identical information (Richardson-Klavehn & Bjork, 1988; Neely, 1991).

This phenomenon has been explained in terms of Morton's (1969) logogen theory. According to the model, each of the words in the mental lexicon is represented by a logogen. Each logogen is associated with a resting level of activity. When a word is identified the level of activity associated with the corresponding logogen is increased above its normal resting level where it remains for a period of time. This change in the level of activity associated with the logogens and the words they represent is believed to be responsible for priming effects.

The N400 response appears to be tied to the change in activity level that is associated with the logogens. These activity levels of target words can be altered through the prior presentation of either semantically related or identical stimuli. In both cases the presentation of these priming stimuli increases the activity levels of the logogens that represent target words. When the activity levels associated with logogens are increased above their normal level a N400 response is not produced by the target words. However, a N400 response is observed to stimuli that have not been semantically primed or preceded by the identical stimuli. Thus, the N400 response is believed to reflect the extent to which target stimuli have been primed by the preceding context in which they were presented.

Much research has been aimed at understanding the processes reflected by the N400 response using both semantic and repetition priming paradigms. One of the first investigations of semantic priming using ERPs and behavioural responses in a lexical decision task was conducted by Bentin, McCarthy and Wood (1985). In this experiment, the words were preceded by either semantically related or unrelated words. Behavioural testing showed that the responses to words which were preceded (i.e., primed) by semantically related words had significantly shorter latencies than those to words that were preceded by semantically unrelated words.

Electrophysiological assessments showed that different ERP responses were elicited by primed and unprimed words. The N400 amplitudes that were elicited by the unprimed words were significantly larger than those that were elicited by primed words. These findings indicate that the N400 was sensitive to whether the stimuli were primed. The results of this experiment were consistent with behavioural research and indicated that ERPs could be a valuable tool in the investigation of language.

A further study by Koyama, Nageishi and Shimokochi (1992) investigated the extent to which the primes were related to target words in a lexical decision task. The primes were either semantically related, neutral or semantically unrelated to the targets. ERPs and behavioural data were recorded for each of the targets with the prediction that the amplitude of the N400 response would be sensitive to the degree to which the primes were semantically related to the targets. The results of the study supported this prediction.

The response latencies observed in each of these conditions differed significantly from all of the other conditions. That is, the targets that were preceded by semantically related primes had significantly shorter latencies than did those that were preceded by neutral or semantically unrelated primes. In addition, the response latencies associated with targets preceded by neutral primes were significantly shorter than those preceded by semantically unrelated primes. This pattern of results indicates that the degree to which the primes and targets were semantically related influenced task performance.

Similar results were obtained from the ERP data. The unrelated condition produced a N400 response that was significantly larger in amplitude than those elicited by both the neutral and semantically unrelated conditions. The N400 amplitudes that were associated with the neutral and semantically unrelated conditions did not differ from each other. The observation that larger N400 responses elicited by targets that were preceded by semantically unrelated primes is consistent with the findings from Bentin et al.'s (1985) study. Together these findings demonstrate that the N400 response reflects the extent to which the stimuli can be expected to occur as a consequence of priming.

Additional support for this position was obtained from a sentence reading task (Kutas & Hillyard, 1984). Kutas and Hillyard (1984) investigated whether the N400 response is sensitive to the degree to which stimuli can be anticipated to occur. They manipulated the level of predictability using a design that was similar to Kutas and Hillyard (1980a, Experiment 3). In these studies all of the terminal words completed the sentences in a congruous manner, however, the predictability of the terminal words for the sentences was manipulated by varying the level of contextual constraint of the sentences. The sentences that were used in the study had either high, medium or low levels of contextual constraint. The level of contextual constraint that was used in the sentences determined the extent to which the subjects could anticipate a particular terminal word (Shannon, 1948).

In contrast to their earlier study Kutas and Hillyard (1984) also varied the levels of cloze probability for the terminal words of the sentences. The words that were used to complete the sentences most frequently were considered to have high cloze probability regardless of the level of contextual constraint. Terminal words that were used less frequently than high cloze probability words were considered to have a medium level of cloze probability. Finally, terminal words that were rarely used to complete the sentences were considered to have a low level of cloze probability. Thus, terminal words representing each level of cloze probability were used to complete sentences within each level of contextual constraint.

ERPs were recorded to the terminal words of the semantically congruous sentences. Based on the findings reported by Kutas and Hillyard (1980a) it was predicted that the amplitude of the N400 response would be determined by the contextual constraint of the sentences. In addition, Kutas and Hillyard (1984) predicted that the size of the N400 response would be determined by the cloze probability of the sentence-ending words. The results of the study supported these predictions: the contextual constraint and cloze probability of the terminal words influenced the amplitude of the N400 response.

Inasmuch as the sentence-ending words were semantically appropriate for the sentence context these results indicate that the N400 response was not dependent upon the presence of a semantic incongruity. Rather, the amplitude of the N400 responses increased as the level of cloze probability of the terminal words decreased. That is, the terminal words that had a low level of cloze probability produced larger N400 responses than did terminal words that had a high level of cloze probability. According to Kutas and Hillyard (1984) the N400 component proved to be more sensitive to the level of cloze probability than to the level of contextual constraint. Their conclusion was based on the observation that the N400 responses produced by terminal words with low cloze probability did not differ significantly in amplitude regardless of the level of contextual constraint used in the sentences.

Further, the results showed that sentences with a medium level of contextual constraint were responded to differentially depending upon the level of cloze probability of the congruous terminal words. The terminal words that had a low level of cloze probability for the sentences produced significantly larger N400 responses than those having higher levels of cloze probability. These findings suggest that the level of cloze probability influenced the amplitude of the N400 response. However, the waveforms indicate also that the level of contextual constraint influenced the amplitude of the response independent of the effect of cloze probability.

The ERPs that were recorded to terminal words with high cloze probability appeared to differ across the three levels of contextual constraint. That is, the amplitude of the N400 response increased as the level of contextual constraint decreased. Although this observation was not reported by Kutas and Hillyard (1984) the presence of this relationship suggests that the level of contextual constraint influenced the level of predictability for particular terminal words. Overall, these findings suggest that the degree to which terminal words were anticipated influenced the amplitude of the N400 response. Further, the level of predictability was determined by both the contextual constraint of the sentences and the level of cloze probability held by the terminal words.

The gradient observed in the amplitude of the N400 response was attributable to the fact that lower levels of contextual constraint make terminal words less predictable. That is, the average level of high cloze probability for the terminal words of sentences with high contextual constraint is much higher than that for sentences with medium and low levels of contextual constraint. Therefore, even though the terminal words of low contextually constrained sentences are considered to have high cloze probability these words are still less predictable than words with high cloze probability that complete sentences with high contextual constraint. These findings indicate that the amplitude of the N400 response reflects the extent to which the terminal words of sentences deviate from the words that were primed by the sentence context. A similar gradient in N400 amplitude was observed by Kutas, Lindamood and Hillyard, (1984) in a semantic categorization task, and by Van Petten and Kutas (1990) in a sentence reading task that manipulated the predictability of occurrence of high and low frequency words.

Additional evidence indicating that the N400 response is sensitive to the predictability of stimuli was reported by Kounios and Holcomb (1992). In their study the semantic relationship between categories and exemplars in a sentence was manipulated. Each sentence consisted of a subject-segment (e.g., ALL DOGS ARE) and a predicate-segment (e.g., ANIMALS). In half of the sentences the subject-segment contained a category exemplar (e.g., DOGS) and the predicate-statement contained the category name (e.g. ANIMALS) and in the remaining half the order was reversed. The category and exemplar that were presented in each sentence were either semantically related or unrelated to each other. Finally, the quantifier that was used to initiate the sentences was manipulated in three ways. The quantifiers were either ALL, NO or SOME. This manipulation permitted an investigation of the truth value of the sentences.

The subjects were asked to read each sentence and decide whether it was true or false by making a button press after the presentation of the predicate-segment of each sentence to indicate its validity. The results of the behavioural data indicated that the response latencies were influenced by the degree of semantic relationship between the categories and exemplars. Significantly longer latencies were observed when the categories and exemplars were semantically related in comparison to when they were unrelated. In addition, the order in which the categories and exemplars appeared in the sentences influenced the reaction time. Longer latencies were observed when the subject-segment contained the category and the predicate-segment contained the exemplar than when the order was reversed. Finally, the response latency was influenced by the particular quantifier that initiated the sentences. Sentences that were initiated by the SOME quantifier were responded to faster than sentences initiated by ALL and NO quantifiers. The sentences that were initiated by the ALL quantifier were responded to faster than those initiated by the NO quantifier.

ERPs were recorded to both the subject-segment and the predicate-segment in each sentence. Unlike the behavioural results, the ERP data showed that the N400 response was not sensitive to the truth value of the sentences. Rather, the N400 responded to the degree of semantic relationship that existed between the category and the exemplar. That is, the amplitude of the N400 was significantly larger when these terms were semantically unrelated in comparison to when they were semantically related. Further, the order in which these terms were presented influenced the amplitude of the N400. A significantly larger N400 response was elicited by exemplars that were presented as the predicate-segments than when the exemplars were presented as the subject-segments. These findings indicate that the N400 response was sensitive to the semantic relationship of the categories and exemplars. Moreover, the observation that the order of presentation influenced the N400 amplitude provides evidence that this component is sensitive to the predictability of the exemplars.

As indicated previously, the amplitude of the N400 response is also sensitive to repetition priming. Research conducted by Fischler and Raney (1991) showed that the N400 component responded differentially to two equally plausible exemplars as a consequence of repetition priming. In their study, subjects viewed a videotape containing a number of everyday objects. After viewing the videotape, subjects read a series of two-phrase statements that depicted a valid semantic relationship. In these statements the first phrase acted as a semantic cue for the second phrase. The second phrase contained the names of objects that were valid exemplars of the categories that had been named in the first phrase (e.g., electronics - stereo). Some of the objects that were named in the second phrases of the statements had been viewed in the videotape. This is referred to as repetition priming since subjects had actually viewed these objects in the videotape prior to engaging in reading the two-phrase statements. ERPs were recorded to the second phrase of the statements.

The results indicated that the objects that were viewed prior to reading the statements produced different patterns of ERP responses than did the unviewed objects. A large N400 response was observed to the second phrase when it contained the name of an object that was not viewed in the videotape. In contrast, a N400 component was not observed when the second phrase named an object that had been presented in the videotape. Since both of the objects named in the second phrases of the statements were valid exemplars of the categories depicted in the first phrase, the difference in ERP patterns cannot be attributed to semantic priming. Rather, these findings indicate that the N400 response can be elicited differentially as a consequence of repetition priming. Similar results demonstrating the sensitivity of the N400 response to repetition priming has been investigated extensively using a number of different paradigms (e.g., Kuperman, Porjesz, Arndt, Bauer, Begleiter, Cizadlo, O'Connor, & Rohrbaugh, 1995; Rugg, 1987). A reduction in the amplitude of the N400 response has been demonstrated in word pair paradigms with both high and low frequency words (Rugg, 1990; Young & Rugg, 1992; Rugg, Cox, Doyle, & Wells, 1995), semantic categorizations (e.g., Young & Rugg, 1992; Polich, 1985), in the same and different contexts (Rugg, Doyle, & Holdstock, 1994), using different interim lags (Nagy & Rugg, 1989; Rugg & Nagy, 1989; Rugg et al., 1994) and both within and across modalities (Holcomb & Neville, 1990; Rugg, Doyle, & Melan, 1993).

The sensitivity of the N400 to both repetition and semantic priming has led researchers to consider investigating commonalities in processing that might exist between these forms of priming. A study conducted by Rugg (1985) compared the effects of semantic and repetition priming in a lexical decision task. In this task subjects responded to unprimed words as well as to targets that had been primed by either a semantically related word or by the same word. Evidence of priming was obtained from the behavioural results which showed that semantic priming and repetition priming produced shorter response latencies than those words that had not been primed. Further, the latencies associated with repeated stimuli were significantly shorter than those primed by semantically related words. Similar results were obtained from the ERP data.

The N400 responses that were associated with unprimed words were significantly more negative than words that had been primed by either semantically related or identical stimuli. In addition, the effect of repetition priming was greater than that of semantic priming. This effect was demonstrated by the significantly smaller N400 responses that were elicited by the repeated stimuli than by the semantically primed stimuli. Additional support for the sensitivity of the N400 response to repetition has been obtained from sentence reading tasks. Recent research has investigated the relationship between semantic and repetition priming in a sentence reading task (Besson, Kutas, & Van Petten, 1992). Subjects were required to read a series of sentences that had terminal words that were either congruous or incongruous to the sentence context. These congruous and incongruous sentences were presented to subjects in two experiments. In the first experiment the sentences were repeated once and in the second experiment the sentences were repeated twice. ERPs were recorded to the terminal words of the sentences each time they were presented.

An effect of repetition was observed in the ERP data. The results from Experiment 1 showed that the N400 amplitudes that were associated with the first presentation of the semantically incongruous terminal words were significantly larger than those associated with congruous terminal words and the ERP responses that were associated with the first and second presentations of the semantically congruous terminal words did not differ. However, the amplitude of the N400 response that was elicited by the second presentation of the incongruous terminal words was significantly reduced in comparison to the first presentation. Further, the N400 response that was elicited by the second presentation did not differ from those produced by congruous terminal words.

In the second experiment, the congruous and incongruous sentences were presented to subjects three times. As in Experiment 1 the amplitude of the N400 elicited by the first presentation of the semantically incongruous terminal words was significantly larger than those observed to the second and third presentations. However, the N400 amplitudes that were associated with the second and third presentations of the incongruous stimuli did not differ from each other. Further, the N400 responses elicited during the second and third presentations of the incongruous sentences did not differ from the amplitudes elicited by congruous endings. These results indicate that the amplitude of the N400 response was sensitive to stimulus repetition.

These findings have been supported by subsequent research. A recent study by Mitchell, Andrews and Ward (1993) investigated the effect of repetition during a sentence reading task. This study consisted of two phases. In the first phase of this study, the subjects were required to familiarize themselves with a series of unrelated sentences that were completed using semantically congruous or incongruous terminal words. After reading these sentences the second phase of the study began. During the second phase the subjects were presented with another series of sentences. One third of these sentences had been previously presented in the first phase of the study (i.e., Old Sentences) and were presented in exactly the same manner during the second phase. Another third of the sentences was presented and had not been viewed in the previous phase (i.e., Completely New). A final third of the sentences had been presented in the first phase but had been re-paired so that the sentence contexts were now completed with different terminal words (i.e., New Pair). ERPs were recorded to the terminal words of these sentences.

It was predicted that the N400 response would be sensitive to the number of stimulus repetitions. The results of the study supported this hypothesis and showed that the N400 response varied across the stimulus conditions. A N400 response was elicited by the semantically incongruous terminal words in the Completely New condition which was significantly larger in amplitude than those elicited by the incongruous endings in both the Old Sentence and New Pair conditions. Further, the N400 amplitudes that were associated with the New Pair condition were significantly larger than those associated with the Old Sentence condition. In contrast to Besson et al. (1992), who did not observe a reduced amplitude to repeated congruous stimuli, an effect of repetition was also observed to terminal words that completed sentences in a congruous manner. These findings provide evidence that the number of stimulus repetitions influenced the amplitude of the N400 responses. It is possible that repeated presentations of sentences allowed subjects to anticipate the anomalous endings and as a result the N400 was not elicited. These findings suggest that the N400 component can be systematically diminished by reducing subjects' uncertainty about the word being presented regardless of its semantic appropriateness.

A more naturalistic study was conducted to investigate the effect of semantic congruity and repetition on the N400 response (Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). In this study, subjects read articles that had been selected from some popular magazines. ERPs were recorded to words that were repeated throughout the articles. The repetition of words in this study occurred naturally throughout the discussion of the articles' topics rather than artificially as in other research. It was predicted that the amplitudes that were associated with the second presentation of both high and low frequency words would be reduced in comparison to their first presentation. The results of the study supported this prediction. This study is particularly significant since the paradigm more closely resembles naturalistic reading than previously reported paradigms.

Research indicates that priming can systematically affect the expression of the N400 component in such procedurally different tasks as reading word lists and sentences. Further, the N400 is sensitive to both semantic and repetition priming. These forms of priming appear to have a similar influence on the amplitude of the N400 response. However, it has been suggested that semantic and repetition priming may actually reflect different cognitive processes (Rugg, 1985; 1987). Support for this position has been obtained from studies reporting that repetition effects are stronger (Dannenbring & Briand, 1982; Wilding, 1986) and more persistent than semantic priming effects (Scarborough, Cortese & Scarborough, 1977; Jacoby & Dallas, 1981).

An ERP study conducted by Rugg (1987) showed that while both repetition and semantic priming reduced the amplitudes of the N400 response, the topographical distributions that were associated with these two forms of priming were different. Semantic priming was associated with an anterior distribution whereas, repetition priming was associated with a more widely spread distribution of neural activity. It was suggested that these two forms of priming reflect separate cognitive processes.

Although Rugg (1987) has suggested that these differences in topographical distributions are indicative of different cognitive processes there is as Rugg notes, evidence suggesting that semantic congruity and repetition influence a common stage of lexical processing (Besson et al., 1992). Overall, there is good evidence that semantic and repetition priming can systematically affect the expression of the N400 component in such procedurally different tasks as reading word-lists and sentences.

Orthographic and Phonological Priming and the N400 Component

The N400 response has also been held to be sensitive to priming manipulations that require subjects to focus on either the orthographic or phonological characteristics of the stimuli. Research investigating the factors responsible for producing the N400 component indicates that it can be elicited during a variety of different linguistic tasks. In all of these tasks the amplitude of the N400 component has been shown to be inversely related to the level of expectancy for words that has been generated through priming (Kutas & Hillyard, 1984). In the studies considered to this point, the semantic expectancies have been generated by employing semantic and repetition priming. Recent research suggests that a N400 component may also be observed when the experimental manipulations direct subjects to focus on the orthographic and phonological codes that are associated with words in a word pair task.

A study conducted by Sanquist, Rohrbaugh, Syndulko and Lindsley (1980) emphasized the semantic, orthographic and phonological representations of words in a word pair task. Subjects were required to decide whether words in a pair were the "same" or "different". The words were judged to be the "same" if they were synonyms, appeared in the same type case (i.e., upper or lower case), or rhymed, respectively. The words were judged to be "different" if they violated any of these criteria. ERPs were recorded during the presentation of the word pairs.

The authors were concerned with the influence of the experimental manipulation on the amplitude and latency of the P300 response. Consequently, no data concerning the N400 component were reported. However, an examination of the data by Kutas and Van Petten (1988) suggested that a N400 response was elicited by semantic, orthographic and phonological mismatches when the task instructions caused them to focus on detecting these sorts of deviations. Kutas and Van Petten's re-analysis of Sanquist et al.'s (1980) data revealed that a component with negative polarity was elicited by the second words in the word-pairs when they were semantically unrelated to the first words. In addition, negative components were observed to the second words in the word-pairs both when they did not rhyme with the first words and when they were visually dissimilar from the preceding words.

Kutas and Van Petten (1988) suggested also that a N400 response was elicited in a related word pair task. Polich, McCarthy, Wang and Donchin (1983) investigated the independence of orthographic and phonological codes in a word-pair task. In this experiment subjects were asked to decide if words in a word-pair were visually similar or if they rhymed. Four conditions manipulated the visual and phonological similarity of the words in the word-pairs. The word-pairs were either both visually similar and rhymed (Condition A), visually similar but did not rhyme (Condition B), visually dissimilar but rhymed (Condition C) or were both visually dissimilar and did not rhyme (Condition D).

ERPs were recorded to the word-pairs presented in the study. Insofar as the authors were concerned with the effect of the manipulation on the P300 response they did not investigate the N400 data. However, an examination of Polich et al.'s (1983) data by Kutas and Van Petten (1988) suggested that orthographic and phonological codes are activated independently. The results reported by Polich et al. (1983) revealed that a negative component was elicited during the rhyming task by the second words of the word-pairs when they did not rhyme with the preceding words. This effect was observed regardless of whether the words in the word-pair were considered to be orthographically similar to each other. In addition, a negative component was elicited during the visual matching task when the second words of the word-pairs when they were visually dissimilar to the first words. Further, this effect occurred independently of phonemic similarity.

A study by Kramer and Donchin (1987) attempted to replicate the findings reported by Polich et al. (1983) using the identical stimuli and design. Kramer and Donchin (1987) observed a component with a negative polarity that occurred approximately 350 ms post-stimulus. This negative response was largest when the orthographic and phonological representations of the words in the word pairs were mismatched and was smallest when these representations were matched. The amplitudes associated with word pairs that matched either orthographic or phonological representations were intermediate in size. To the extent that this negative component can be interpreted as a N400 component it showed the same pattern as the N400 response Kutas and Van Petten (1988) suggest occurred in Sanquist et al.'s (1980) study. Similar differences in N400 amplitude were observed between the stimulus conditions that required subjects to focus on orthographic and phonological codes (Rugg & Barrett, 1987; Rugg, 1984). Overall, these findings suggest that the N400 component is sensitive to orthographic and phonological representations when these codes are task relevant.

Earlier Occurring Negative Components

The N400 component has been demonstrated to be sensitive to the cognitive processes that are associated with priming during linguistic tasks. It has to be recognized that in addition to the N400 component, earlier negative-components (e.g., N200, processing negativity, mismatch negativity) are apparent in ERP studies. These components are thought to reflect processes that occur earlier in the processing sequence because they are associated with shorter latencies than those associated with the N400 response. Further, these earlier components have been shown to differ from the N400 component in terms of their topographical distribution pattern. Whereas the N400 response is typically most apparent over centro-parietal brain areas (Kutas & Van Petten, 1988) these earlier occurring components tend to be observed over fronto-central areas (Nätäänen, Simpson, & Loveless, 1982).

It has been pointed out that the N400 response is sensitive to violations in semantic expectancy that are based on long-term memory. Research suggests that these earlier occurring N2-type components respond primarily to violations in stimulus expectancy and mismatches that are based upon the physical characteristics of the stimuli (Nätäänen, 1990). That is, they are sensitive to the shorter-term expectancies that are generated by the experimental manipulations used within the study in a manner similar to that observed in studies of the P300 response. More recently however, some evidence has been obtained suggesting that these earlier occurring negative components may also respond to deviations in language processing that are generated by semantic priming during a sentence reading task.

In one such study, Connolly et al. (1992) investigated the N200 component during language processing. Subjects attended to a series of spoken sentences that had either a high or low level of contextual constraint. The terminal words used to complete these sentences were semantically appropriate for the sentence context. However, inasmuch as the level of contextual constraint was manipulated the terminal words for highly contextual constrained sentences were more predictable that those for sentences with low contextual constraint.

Subjects either listened to the sentences or decided whether the sentence-ending words were semantically related to subsequently presented target words. The target words were semantically related and unrelated to the terminal words in equal proportions. Participants heard the sentences either in the presence or absence of a simultaneously presented masking stimulus. The masking stimulus consisted of a mix of twelve competing voices and was presented in one ear while the sentences were presented in the other ear.

The purpose of the masking stimulus was to increase the complexity of semantic processing in an attempt to delay the latency of the N400. The masking manipulation was not expected to influence the elicitation of the N200 component since previous research in the visual modality has shown that the N200 response is not affected by increases in the complexity of perceiving the masked stimuli (Ritter, Simson & Vaughan, 1983; Ritter, Simson, Vaughan & Macht, 1982). ERPs were recorded to the terminal words of the sentences. The results of the study indicated that the use of the masking stimulus influenced semantic processing. The N200 and N400 responses elicited by the unanticipated terminal words of sentences with low contextual constraint were significantly larger than those elicited by terminal words of highly contextually constrained sentences.

The masking manipulation was found to significantly delay the latency of the N400 component relative to the unmasked condition but the latency of the N200 condition was not affected. The observation that these ERP components are elicited differentially supports the view that they are sensitive to different aspects of the language process. The N200 response was observed when the initial phoneme of the terminal words was different from that of the expected terminal words. In contrast the N400 response was elicited by sentence-ending words that were semantically unexpected due to the low level of contextual constraint used in the sentence.

In their subsequent experiment Connolly and Phillips (1994) investigated the processes associated with these components more closely. The authors referred to the negative component which preceded the N400 as the Phonological Mismatch Negativity component (i.e. PMN) rather than the N200 component insofar as the PMN was not elicited by factors that have been reliably demonstrated to produce a N200 response. Whereas the N200 response is typically elicited by infrequently occurring stimuli the PMN component was not sensitive to this manipulation. Further, the PMN was elicited by sentences with low but not high contextual constraint. The authors reasoned that the PMN may have been responding to the unexpected phonological representation of the terminal words of low contextually constrained sentences due to their low level of predictability. This observation suggests that the PMN was an endogenous component rather than a component that responds to the physical characteristics of the stimuli.

Connolly and Phillips (1994) manipulated the terminal words to spoken sentences with high contextual constraint in four ways. The initial phoneme of the terminal words was either phonologically expected or unexpected and the semantic meaning of the words was either congruent or incongruent to the sentence context. ERPs were recorded to the terminal words of the sentences. The results showed that the manipulation of the initial phoneme of the terminal words influenced the latency of the N400 response.

A N400 response was elicited by semantically incongruous terminal words regardless of whether their critical phonemes matched that of the expected high "cloze" terminal words. However, the latency of the N400 was delayed when the initial phoneme of the terminal word was identical to that of the high cloze probability word. The PMN was observed when the initial phoneme of the terminal words differed from that of the high cloze probability words regardless of the semantic appropriateness of the sentence-ending words. This dissociation in the factors responsible for eliciting these components was interpreted as evidence that the processes underlying them were separate and distinct. Further, these findings provide evidence indicating that the earlier occurring negative components are sensitive to deviations in language processing. Unlike the N400 component the PMN appears to be elicited by deviations in the phonological expectancy for the initial phoneme of the terminal words of sentences. Similar findings concerning the sensitivity of the PMN to deviations in language processes that were primed by sentence or picture-spoken word contexts have been reported in other research within the auditory modality (Connolly et al., 1990; Byrne, Dywan, & Connolly, 1995; Connolly, Byrne, & Dywan, 1995). In contrast, evidence has indicated that a negative component occurring earlier than the N400 response was sensitive to deviations in orthographic expectancy in the visual modality (Connolly et al., 1995).

Further indication that the N270 response is sensitive to deviations in orthographic expectancy of the terminal words was obtained in a sentence reading task. A study conducted by Forbes (1993) investigated the use of phonological codes during silent reading. Subjects read a series of unrelated sentences that had a high level of contextual constraint. The terminal words for these sentences were either semantically congruous (CONGRUENT condition) or incongruous. The anomalous terminal words were either phonologically identical to (i.e., homophone foils - FOIL condition) or different from (INCONGRUENT condition) the high cloze probability words. ERPs were recorded to the terminal words of the sentences.

Neither a N270 nor a N400 response was expected to be elicited by the FOIL condition if phonological codes influenced the identification of the sentence-ending words. This prediction was based on the assumption that the phonological codes activated by the stimuli in the FOIL condition would be appropriate even though the terminal word itself was semantically inappropriate. It was expected that both the N270 and N400 components would be elicited by the INCONGRUENT condition because the stimuli in this condition violated the orthographic and phonological expectations for the expected terminal words. Neither component was expected to occur in response to the CONGRUENT condition in which terminal words were both semantically and phonologically appropriate.

As expected, a N400 response was elicited by the INCONGRUENT condition but not by either the FOIL or CONGRUENT conditions. Since the terminal words presented in the FOIL conditions differed from the terminal words in the INCONGRUENT condition only in terms of their phonological correctness it seems phonological representations of the terminal words in the FOIL condition played an important role in mediating the word identification process. Although the N400 response was not elicited by the FOIL condition a N270 response was elicited by the sentence-ending words in this condition. Inasmuch as the phonological representations for the semantically incongruous homophone foils were identical to their homophone partners, it seemed reasonable to assume that the elicitation of the N270 component was due to deviations in the orthographic expectancy associated with terminal words in the FOIL condition.

A post hoc analysis compared the N270 responses that were elicited by homophone foils in terms of their orthographic similarity to their homophone partner. Homophone foils were considered to be orthographically similar to their partners if they shared the same initial letter and letter length (Olson & Kausler, 1971). The results showed that larger N270 responses were elicited by homophone foils that were orthographically dissimilar to their homophone partners than to those that were elicited by homophone foils that were orthographically similar to their homophone partners. This finding suggested that the N270 response was elicited by stimuli that violated the orthographic expectation for the expected terminal words of the sentences.

Overall, these findings suggest that ERPs can be used to investigate different processes that are involved in language. The present series of studies used ERPs to investigate the extent to which phonological codes are influential in the word identification process. Variations in the amplitude and latency of the N400 and N270 components were used as indexes of the phonological and orthographic influences during silent reading. In addition, these studies were designed to examine the factors identified in behavioural studies that have been observed to influence the importance of phonological factors during word identification.

Chapter Three

An ERP and behavioural investigation of phonological recoding during silent reading of sentences with homophones

Experiment 1

This experiment was a follow-up study to Forbes (1993) which found evidence for phonological recoding during a sentence reading task. As described previously, the terminal words of these sentences were either semantically congruous or incongruous with the sentence context. Incongruous endings were either phonologically identical to (i.e., homophone foil - FOIL condition) or different from (INCONGRUENT condition) high probability terminal words in the sentences presented. ERPs were recorded to the terminal words of the sentences. It was expected that there would be a differential N400 response to the semantically incongruous stimuli depending upon whether the terminal words met phonological expectations.

The results of the study supported this prediction. A N400 response was elicited by incongruous stimuli that were phonologically unexpected and was significantly greater than the amplitude of the N400 response that was elicited by the incongruous stimuli that conformed with phonological expectations. Insofar as the only difference between the terminal words in these conditions was that the stimuli in the FOIL condition were phonologically identical to the high cloze probability words it was concluded that phonological codes that were associated with the homophone foils played a prominent role in word recognition. This conclusion was supported by the observation that the N400 amplitudes elicited by the FOIL condition and the CONGRUENT condition did not differ from each other. This finding strongly suggested that the phonological influence took precedence over the effect of violating the semantic expectancy that was generated by the sentence context.

Overall, these findings provide evidence for phonological mediation during silent reading. There is, however, a further issue that requires exploration. Several behavioural studies have reported that whether phonological codes are used during word identification can be influenced by the nature of the experimental task (Jared & Seidenberg, 1991; Stone & Van Orden, 1993). In particular these studies indicate that task variables may determine whether phonological codes are activated (e.g., Rubenstein et al., 1971; Davelaar et al., 1978; Meyer et al., 1974; Martin, 1982, McQuade, 1981; Underwood, Parry & Bull, 1978; Polich et al., 1983; Sanquist et al., 1980; Kramer & Donchin, 1987; Jared & Seidenberg, 1991; Coltheart et al., 1994; McNamara & Healy, 1988; Ferrand & Grainger, 1996; Grainger & Ferrand, 1996). If phonologically based strategies are not effective they may be abandoned in favour of a more effective strategy that presumably would rely upon a different type of code (e.g., orthographic, semantic) (Hawkins et al., 1976; Davelaar et al., 1978).

Manipulations in task instructions have been shown also to alter the use of phonological codes during word identification. A study conducted by Coltheart et al. (1991) investigated the effect of changing task instructions on the use of phonological codes during a semantic categorization task. They reported reduced error rates to homophonic stimuli when subjects were asked to accept only correctly spelled category exemplars. Similar effects were also observed by Coltheart et al. (1994). These findings suggest that manipulations in task instructions that force subjects to attend to orthographic representations reduced the subjects' reliance on phonological codes.

Thus, it is possible that the evidence for phonological recoding observed by Forbes (1993) may have occurred because the subjects were required only to read the sentences -rather than to make decisions with regard to their semantic appropriateness. Therefore, it seems reasonable to presume that phonological codes might not have been used if subjects had to access the meaning of the sentences being read. The objective of Experiment 1 was to determine whether a phonologically based strategy, such as that evident in Forbes (1993), would be abandoned if subjects were required to carry out a reading task demanding full semantic analysis of sentence context and terminal words.

If the processes involved in word identification are altered by the addition of the semantic judgement task and phonological coding becomes less significant, or is abandoned, then a N400 component should be evident in the FOIL condition. In the absence of phonological mediation subjects will presumably use orthographic codes to obtain direct access to the lexicon. Terminal words in the FOIL condition should be correctly identified as semantically incongruous and a N400 component generated. Semantic judgements in the FOIL condition would not be expected to differ in terms of accuracy or latency from the INCONGRUENT and CONGRUENT conditions because orthographic codes were expected to be equally effective in all conditions for determining whether the terminal words were semantically appropriate or not.

However, if phonological mediation does occur then a N400 response should not be observed in the FOIL condition. As in Forbes (1993), the phonological codes that are associated with the homophone foils should lead subjects to assume erroneously that the semantically appropriate homophone was presented. Consequently, the terminal words would not be identified as violating the expectancy for the sentence-ending words that was primed by the sentence context. Further, if the phonological codes associated with the homophone foils activate the semantically appropriate lexical representation, then it seems reasonable to assume that performance on the behavioural task will be less accurate, and longer latencies will be evident in the FOIL condition than the other two conditions.

In addition, the N270 response that was observed by Forbes (1993) was expected to respond differentially to the stimulus conditions based on orthographic mismatches. Forbes (1993) observed that the INCONGRUENT condition produced a N270 response that was significantly larger in amplitude than that observed in the FOIL condition. Further, the amplitudes observed in the FOIL condition were significantly larger than those observed in the

CONGRUENT condition. Thus, the N270 component appeared to be sensitive to deviations in the orthographic expectancy for the terminal words of sentences. This position was supported by the post hoc analysis of the FOIL condition which revealed that the N270 was only elicited by homophone foils that were orthographically dissimilar to their homophone partner. Insofar as there was no reason for presuming that the inclusion of the behavioural task would influence the elicitation of the N270 response the same pattern of findings was anticipated to occur in the present study.

Method

Subjects

Twelve (males=4, females=8) native English speaking students with a mean age of 23 years (range=18-33) and normal or corrected-to-normal vision participated. Subjects were dextral (Oldfield, 1971) with the Laterality Quotient ranging from 50 to 100, and were screened for reading ability (M=81.2 percent, SD=5.21; range=71.9-88 percent) using the Nelson-Denny Reading Comprehension test (Nelson & Denny, 1976). Inasmuch as all subjects performed well on the Nelson-Denny test none of the participants were excluded from the experiment as a result of this test score. Course credit was given for participation. Informed consent was obtained prior to initiating the experiment.

Apparatus

Stimuli

A series of unrelated sentences with a high level of contextual constraint were presented in this study. The target stimuli were 114 homophone units. A homophone unit consisted of two words with identical pronunciations but different derivations, meanings and spellings (Kreuz, 1987). Norms indicating the frequency with which each of the individual homophones within a homophone unit was produced in an oral spelling task were obtained from a separate pool of undergraduate subjects (N=44). Within each homophone unit one homophone was spelled with a high frequency (HSF) and the other with a low frequency (LSF) (See Appendix A, Table A1 for spelling frequency norms).

Equal numbers of HSF and LSF homophones were used to complete highly contextually constrained sentences that ranged in length from 4 to sixteen words (M=8.6; Mode=8); Seventy-eight percent of the sentences were between 7 and eleven words in length. A pilot study using a separate pool of undergraduate volunteers (N=40) had subjects generate terminal words to sentences (in a manner similar to Bloom & Fischler, 1980) to ensure the sentences used in the study phase had high contextual constraint and high cloze probability (Shannon, 1948; Taylor, 1953) (See Appendix A, Table A2 for sentence stimuli).

One-third of the sentences were completed with semantically incongruent homophones that did not share their phonological representation with the high cloze probability words for the sentences (INCONGRUENT condition). One-third of the sentences were completed with the homophone from a homophone pair that was semantically congruous to the sentence context (CONGRUENT condition). These sentence-ending words had high cloze probability for the sentences and had been primed by the sentence context. The final third of the sentences were completed with phonologically expected but semantically incongruous homophones (FOIL condition). See Table 1 for examples of sentences from the stimulus conditions.

The terminal words from the CONGRUENT and FOIL conditions were counterbalanced so that each homophone from a homophone pair appeared in both stimulus conditions. That is, the high and low spelling frequency homophones from a homophone pair were each presented in the CONGRUENT and FOIL conditions. Since each subject could only be exposed to one homophone (high or low spelling frequency) in either stimulus condition (CONGRUENT or FOIL) four different experimental versions of the sentence reading task were required. Thus, a high spelling frequency homophone (e.g., BEAR) completed a sentence in the CONGRUENT condition in Version A whereas the corresponding low spelling frequency homophone.

Table 1

Experimental Design used in Experiment 1.

Stimulus Conditions	Sentence Example	Number of Trials
Congruent		
High Spelling Frequency	The dove is a sign of **peace**.	19
Low Spelling Frequency	The class baked a cake and everyone had a **piece**.	19
Foil		
High Spelling Frequency	The class baked a cake and everyone had a **peace**.	19
Low Spelling Frequency	The dove is a sign of **piece**.	19
Incongruent		
High Spelling Frequency	Many people eat peanut butter and jelly **wave**.	19
Low Spelling Frequency	The car ran out of **bawl**.	19

Note: Terminal words were not presented using boldface type in the experiment.

A total of 114 trials were presented in Experiment 1.

(e.g., BARE) completed a sentence in the CONGRUENT condition in Version B. In addition, the same high spelling frequency homophone was used to complete a sentence in the FOIL condition in Version C and the corresponding low spelling frequency homophone was used to complete a sentence in the FOIL condition in Version D. In contrast, the terminal words that were used to complete sentences in the INCONGRUENT condition were the same across all four experimental versions.

There were six types of sentences (19 per condition) presented in the experiment (i.e., two levels of spelling frequency X three conditions). All 6 types of sentences were presented to each of the subjects. Each subject was exposed to a total of 114 sentences during the experiment. Block randomization determined the order in which the four study versions were presented.

A behavioural response was made to each of the sentences presented in the experiment. Subjects were required to press a button to indicate whether each sentence was completed with a semantically congruous or incongruous word. The left and right outermost buttons of a four-button keypad (with horizontally arranged buttons) were used to register responses. The particular button (i.e., left or right) used to indicate that the sentences were semantically congruous or incongruous was counterbalanced across subjects.

Stimulus Presentation and Physiological Recording

During the presentation of the sentences the subjects were seated in a dimly lit, sound attenuated room approximately 1 metre from a computer monitor on which the words in the sentences were presented one at a time. Each word was presented for a duration of 250 ms and the interval used between the words was 750 ms. There were 3 seconds between sentences. The terminal words that were used to complete the sentences ranged in length from 1 to 7 letters (*M*=4.38; Mode=4; Eighty-five percent of the words were between 3 and 5 letters in length). The mean visual angle subtended by these sentence-ending words was 3.7 degrees (range=.74-5.21 degrees).

The electrophysiological responses that were elicited by the terminal words of the sentences were recorded using a grounded cap. The electrode cap contained tin electrodes positioned at Fz, F3, F4, F7, F8, Cz, C3, C4, Pz, P3, P4, T3, T4, T5 and T6 with linked ears as a reference. Vertical and horizontal electro-oculographic (EOG) activity was recorded with electrodes placed supraorbitally and over the outer canthus of the left eye (Connolly & Kleinman, 1978). Electrode impedance was maintained at or below 5 KΩ to ensure that the recording signal was acceptable. EEG recordings were made with a half-amplitude bandpass of 0.01 - 100Hz (0.01 Hz is equal to a 5 second time constant) and were sampled at 500 Hz for 100 ms before and 1000 ms after the terminal word. Trials contaminated by EOG activity greater than 75 μV were excluded from analysis. Individual waveforms were filtered digitally prior to scoring using a bandpass of 0.1 - 35 Hz.

Data Analysis

ERPs that were collected from each electrode site for each individual were obtained by averaging the EEG activity that was recorded to the sentence-ending words within each stimulus condition. The ERPs for each individual were then averaged together to obtain grand average waveforms that reflected the general ERP pattern for the entire group of subjects in the different stimulus conditions. The amplitude and latency data for both the N270 and N400 components were obtained using the peak identification method. That is, the N270 component was scored as the most negative point between 200 - 350 ms and the N400 component was scored as the most negative point between 350 -650 ms.

The data were scored by the author who was not blind to the stimulus conditions. However, two important criteria were adhered to during the scoring of the data. First, the amplitude of the components was calculated as the voltage difference between the mean activity for the 100 ms period prior to stimulus onset and the point scored as the most negative within a specified latency range. Second, the latency of the components was calculated as the time from stimulus onset to the point scored as most negative.

The amplitude and latency data that were obtained from the individual averaged waveforms were analyzed with a repeated measures analysis of variance using Greenhouse-Geisser conservative degrees of freedom (Greenhouse & Geisser, 1959). The data were analyzed in two different ways. The first analysis of the data included Frequency (2 levels), Condition (3 levels) and Site (15 levels) as factors in an ANOVA.

The second analysis was conducted to simplify the assessment of amplitude differences that were observed across the scalp. This approach facilitates the assessment of topographical differences by investigating the data associated with specific brain areas and hemispheres. This analysis included Condition (3 levels) as one factor and the electrode sites were divided into two factors: Hemisphere (2 levels) and Region (4 levels). The 4 levels of the Region factor were frontal, temporal, central and parietal. The 2 levels of the Hemisphere factor were left hemisphere and right hemisphere. These factors were analyzed in an ANOVA with repeated measures.

The left frontal region was represented by combining the data from F3 and F7 electrode sites together and the right frontal region was represented by combining the data from F4 and F8 electrode sites together. Similarly, the data from T3 and T5 electrode sites were combined to represent the left hemisphere temporal value and the data from T4 and T6 electrode sites were combined to represent the right hemisphere temporal value. The left and right central brain regions were represented by data collected from C3 and C4 electrode sites, respectively. Finally, the left and right parietal brain regions were represented by data collected from P3 and P4 electrode sites, respectively. The midline sites were excluded from this analysis.

Orthogonal planned comparisons were used to investigate the predicted differences between the stimulus conditions. See Table 2 for the comparisons that were used to address the

Table 2

Orthogonal comparisons that were performed for N270 and N400 amplitude data in each of the experiments

N270 Component

Experiment 1	Experiment 2	Experiment 3	Experiment 4
Incongruent vs. Foil	Foil vs. Congruent	Foil vs. Congruent	No N270 component
Foil vs. Congruent	Foil vs. OS	OSW vs. OSN	
	OS vs. OD	Foil vs. OSN/OSN	
		OSW vs. ODW	
		OSN vs. ODN	

N400 Component

Experiment 1	Experiment 2	Experiment 3	Experiment 4
Incongruent vs. Foil	OS vs. OD	OSW vs. ODW	Congruent vs. Foil
Foil vs. Congruent	Foil vs. OS	OSN vs. ODN	OS-H vs. OS-N
	Foil vs. Congruent	OSW vs. OSN	Foil vs. OS-H
		Foil vs OSW/OSN	PF-H vs. PF-N
		Foil vs. Congruent	Foil vs. PF-H

hypotheses of Experiment 1. All other significant main effects and interactions that were associated with topography were further investigated using Tukey post hoc comparisons. Since the N270 and N400 responses are not associated with a consistent topographical distribution within the visual modality (Connolly et al., 1995) any significant interactions between Conditions and Sites, Regions or Hemispheres were subjected to a normalization procedure. This procedure was performed to equalize the amplitude data observed across conditions so that the effects found could be attributed to real topographical differences amongst conditions rather than to absolute amplitude differences amongst conditions (cf., Glaser & Rutchkin, 1976; McCarthy & Wood, 1985). This procedure removes the amplitude differences between the stimulus conditions in order to determine if the differences across the electrode sites persist. Only interactions remaining significant after normalization are discussed in the text. An alpha level of $p < .05$ was considered statistically significant.

Procedure

The subjects that participated in the experiment were instructed to read silently the sentences that were presented on the computer screen. They were asked to attend to the context of the sentences and were told that the high level of contextual constraint would enable them to anticipate a particular terminal word for each of the sentences. Subjects were also instructed that the sentences may be completed with either semantically congruous or incongruous terminal words and that they were to decide whether each terminal word was semantically appropriate for the sentence context and to indicate their decisions by making a button press as quickly and as accurately as possible. Subjects were instructed not to blink during the presentation of the terminal words so that the artifact associated with eye movements would not contaminate the data.

Results

Electrophysiological Data

N270 Amplitude

Orthographic Similarity

The first analysis of the N270 amplitude data included Frequency (2 levels), Condition (3 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix B Table B1). The results of the analysis showed that the amplitude of the N270 response varied as a function of the stimulus condition. Orthogonal planned comparisons were performed to address the hypotheses of the study. See Table 2.

The first planned comparison investigated the difference in N270 amplitude between the INCONGRUENT and FOIL conditions. As in Forbes (1993) there was a differential N270 response to these twos stimulus conditions. The INCONGRUENT condition was associated with significantly larger N270 amplitudes than the FOIL condition. Inasmuch as the difference between the amplitudes associated with the INCONGRUENT and CONGRUENT conditions was larger than the difference observed between the INCONGRUENT and FOIL conditions the results of this planned comparison also indicated that the terminal words in the INCONGRUENT condition elicited significantly larger N270 responses than did the terminal words in the CONGRUENT condition.

The second planned comparison investigated the difference in N270 amplitudes that was observed between the CONGRUENT and FOIL conditions. In contrast to Forbes (1993) the terminal words in these conditions did not produce significantly different N270 responses. These results suggest that the use of the semantic judgement task influenced the sensitivity of the N270 component to the FOIL condition in a manner that was different from that observed by Forbes (1993) (see Appendix B, Table B2 for means). There were no other significant main effects or interactions observed in this analysis. See Figure 1 for grand averages.

Figure Caption

Figure 1. Grand average waveforms at 15 sites for the CONGRUENT (dotted red line), FOIL (dashed green line) and INCONGRUENT (solid blue line) stimulus conditions presented in Experiment 1.

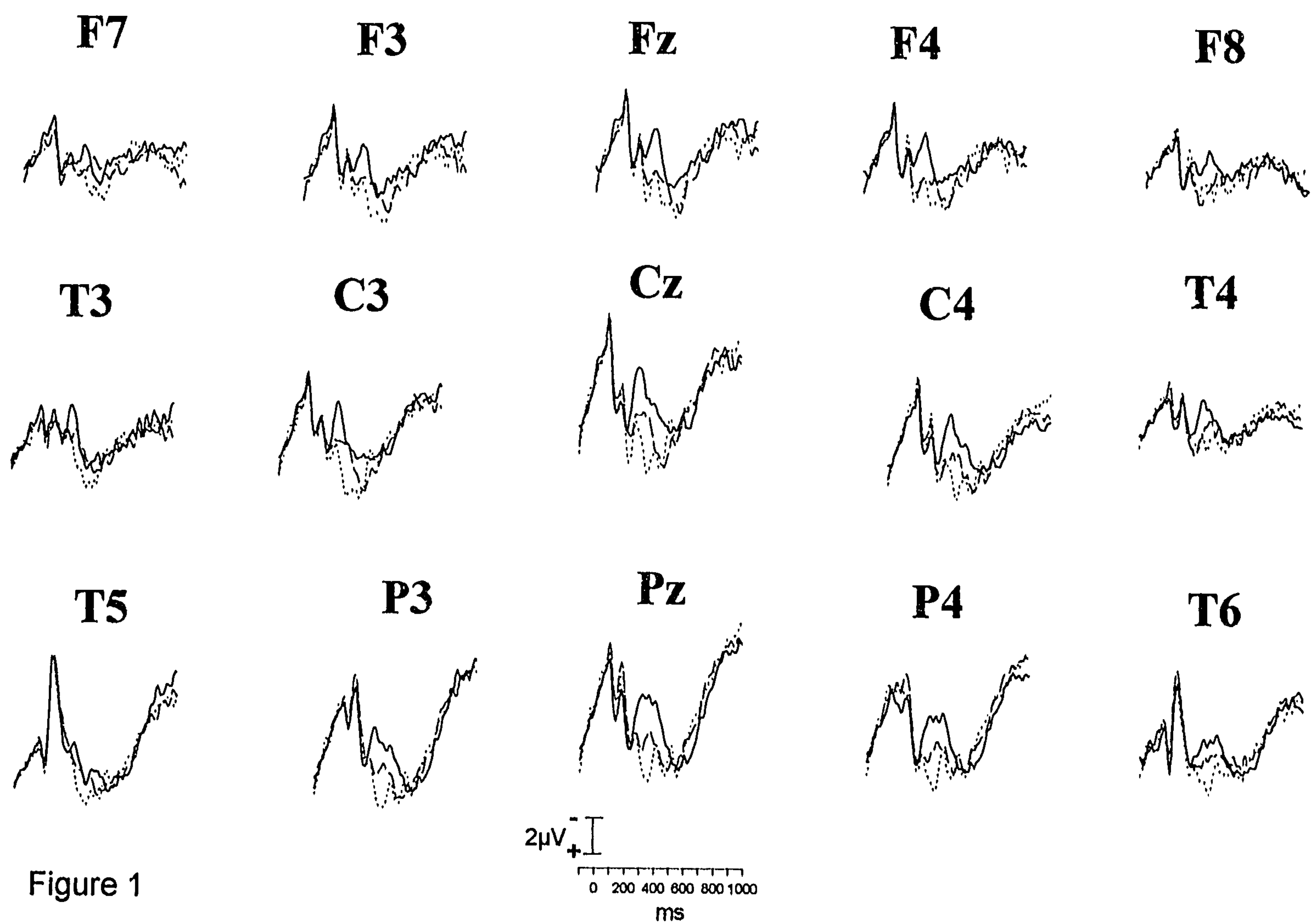
F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
2μV
-
+
0 200 400 600 800 1000
ms

Figure 1

Topographical Distribution of the N270 component

The second analysis of the N270 amplitude data included Condition (3 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix B, Table B3). A significant main effect for the Condition factor was observed as in the previous analysis. This analysis also revealed a significant Region X Hemisphere interaction. A post hoc analysis of this interaction revealed that the amplitudes associated with all left hemisphere regions were significantly larger than those associated with the temporal and parietal regions in the right hemisphere. In addition, the amplitudes recorded over the left temporal area were significantly larger than those recorded over the frontal region in both left and right hemispheres. The amplitudes observed over the left central region were significantly larger than those observed over the right frontal region (see Appendix B Table B4 for means). Overall, these results show that the N270 response was primarily enhanced over the left hemisphere. See Figure 2. No other significant effects were observed.

N270 Latency

There were no significant effects observed in the latency data for either analysis.

N400 Amplitude

Phonological Influences during Reading

The first analysis of the N400 amplitude data included Frequency (2 levels), Condition (3 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix B Table B5). The results of the analysis showed that the amplitude of the N400 response varied as a function of the stimulus condition. Orthogonal planned comparisons were performed to address the hypotheses of the study that were related to phonological influences during reading. See Table 2.

The first planned comparison investigated the difference in N400 amplitude that was observed between the INCONGRUENT and FOIL stimulus conditions. In contrast to Forbes

Figure Caption

Figure 2. Graph depicting a significant interaction between the Region and Hemisphere factors for N270 amplitude data in Experiment 1.

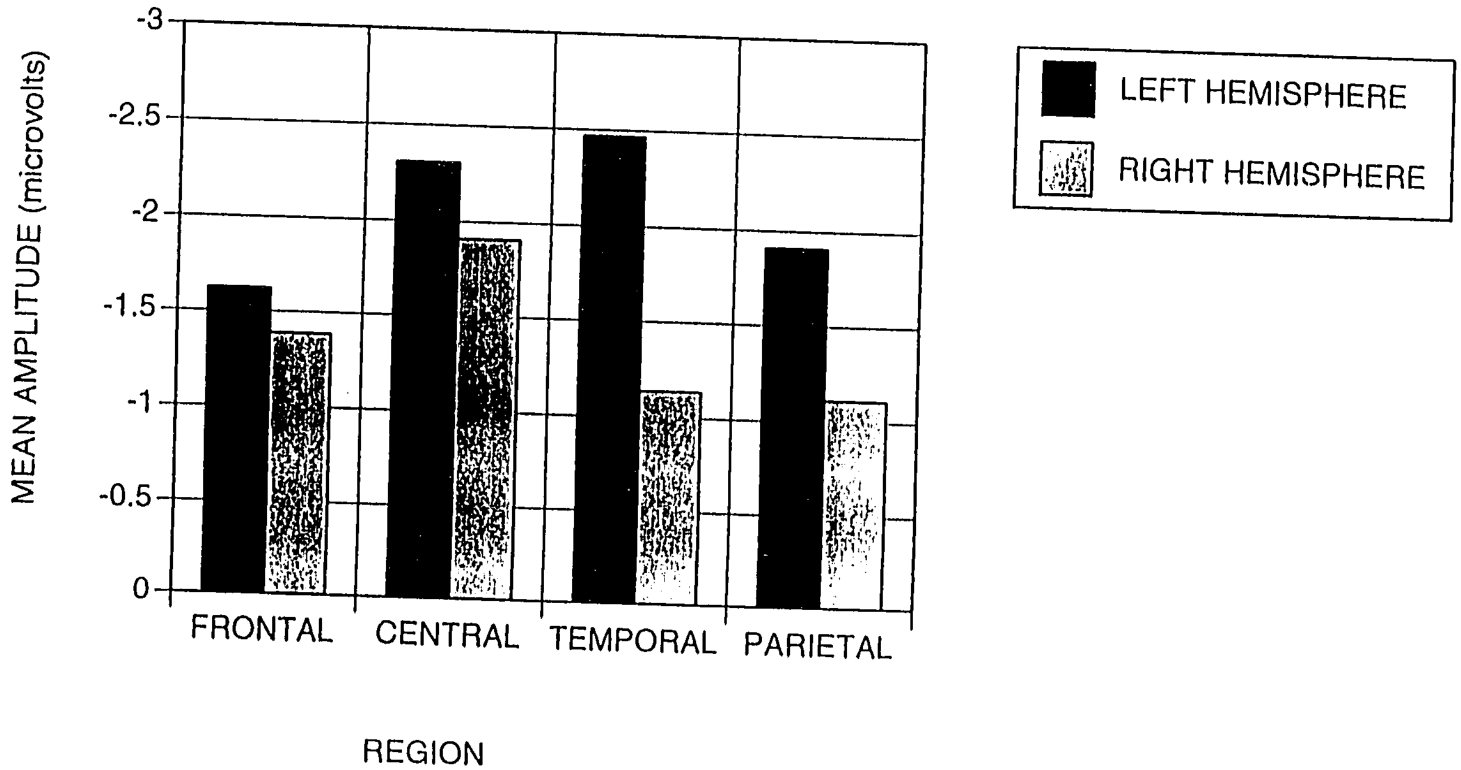
-3
-2.5
-2
-1.5
-1
-0.5
0
MEAN AMPLITUDE (microvolts)
FRONTAL
CENTRAL
TEMPORAL
PARIETAL
REGION
LEFT HEMISPHERE
RIGHT HEMISPHERE

Figure 2

(1993) the N400 did not respond differentially to these semantically incongruous stimuli. Consequently, the N400 amplitudes that were associated with the INCONGRUENT and FOIL conditions were not significantly different indicating that the phonological codes associated with the homophone foils did not overshadow the effect of violating the semantic expectancy that was primed by the preceding semantic context.

This position was supported by the results of the second planned comparison. This comparison investigated the difference in N400 amplitude that was observed between the CONGRUENT and FOIL conditions. In contrast to Forbes (1993) the FOIL condition produced N400 amplitudes that were significantly larger than those produced by the CONGRUENT condition. This finding indicates that the homophone foils were identified as semantically incongruous despite being phonologically identical to the semantically appropriate homophones. Inasmuch as the amplitude difference between the INCONGRUENT and CONGRUENT conditions was larger than that observed between the CONGRUENT and FOIL conditions the results of this comparison also indicated that the N400 amplitudes associated with the INCONGRUENT and CONGRUENT conditions were significantly different from each other (see Appendix B, Table B2 for means). These results suggest that the use of the behavioural task influenced the sensitivity of the N400 response to the FOIL condition in a manner that was different from that observed by Forbes (1993).

Topographical Distribution of the N400 component

A post hoc analysis of the main effect for Site revealed that overall, N400 amplitudes associated with parietal sites were significantly larger than those associated with frontal sites. Specifically, the amplitudes observed over the midline parietal site (Pz) were significantly larger than those observed over the midline frontal (Fz), left frontal (F3 and F7) and anterior temporal (T3) sites (see Appendix B Table B6 for the means of the electrode sites). The interaction between these factors was not significant. As in Forbes (1993) no significant main effects or interactions involving Frequency were observed. Consequently, further ERP analyses collapsed over the levels of spelling frequency.

The second analysis of the N400 amplitude data included Condition (3 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix B Table B7). A significant main effect for the Condition factor was observed which was reported in the previous analysis. In addition, a significant main effect was observed for the Region factor. A post hoc analysis revealed that the N400 response was enhanced at the parietal sites. That is, the amplitudes observed over the parietal regions were significantly larger than those observed over the frontal regions. However, the amplitudes associated with these brain regions did not differ significantly from the central or temporal regions, which also did not differ from each other (see Appendix B, Table B8 for means).

<u>Latency</u>

There were no significant effects observed in either the first or second analysis of the latency data.

<u>Semantic Judgement Task</u>

The reaction time and accuracy data that were associated with the behavioural responses that subjects made to the terminal words of the sentences were analyzed. The data from 9 subjects were used in this analysis since the data collected from 3 subjects were unavailable due to computer file corruption.

<u>Accuracy Data</u>

The accuracy data were analyzed using an ANOVA with repeated measures that included Frequency (2 levels) and Condition (3 levels) as factors conditions (see Appendix B, Table B9). Each condition had 19 trials. This analysis revealed that accuracy levels varied according to the stimulus conditions. A main effect for Condition was observed which post hoc analysis revealed was due to significantly higher levels of accuracy in the INCONGRUENT condition than in either the CONGRUENT or FOIL conditions which did not differ from each other (see Appendix B, Table B10 for means). A main effect for frequency was not observed however, a significant interaction between these factors was observed. Further analysis showed that higher levels of accuracy were associated with the high and low spelling frequency terminal words in the INCONGRUENT condition than with the low and high spelling frequency terminal words in the CONGRUENT and FOIL conditions, respectively (all comparison $p<.05$). See Figure 3.

Latency Data

A repeated measures ANOVA (same factors as above) was conducted on the latency of the correct responses (see Appendix B, Table B11). A significant main effect for Condition was observed which post hoc analysis revealed was due to significantly shorter response latencies in the INCONGRUENT condition than in the CONGRUENT condition. The response latencies that were associated with the FOIL condition did not differ from the other conditions (see Appendix B, Table B12).

A significant Condition X Frequency interaction was observed which further analysis indicated was due to shorter response latencies associated with the high and low spelling frequency terminal words in the INCONGRUENT condition than with the low spelling frequency terminal words in the CONGRUENT condition (M=1160 ms) (all comparisons $p<.05$). See Figure 4.

The accuracy and latency data associated with the incorrect responses were not analyzed since there were too few incorrect responses to permit a reliable statistical analysis to be performed.

Discussion

This study investigated whether evidence for phonological recoding would observed in a sentence-reading task. This study was identical to Forbes (1993) with the exception that a semantic judgement task was included which required subjects to decide whether the terminal

Figure Caption

<u>Figure 3.</u> Graph depicting a significant interaction between Condition and Spelling Frequency factors for frequency of correct responses made on the semantic judgement task in Experiment 1.

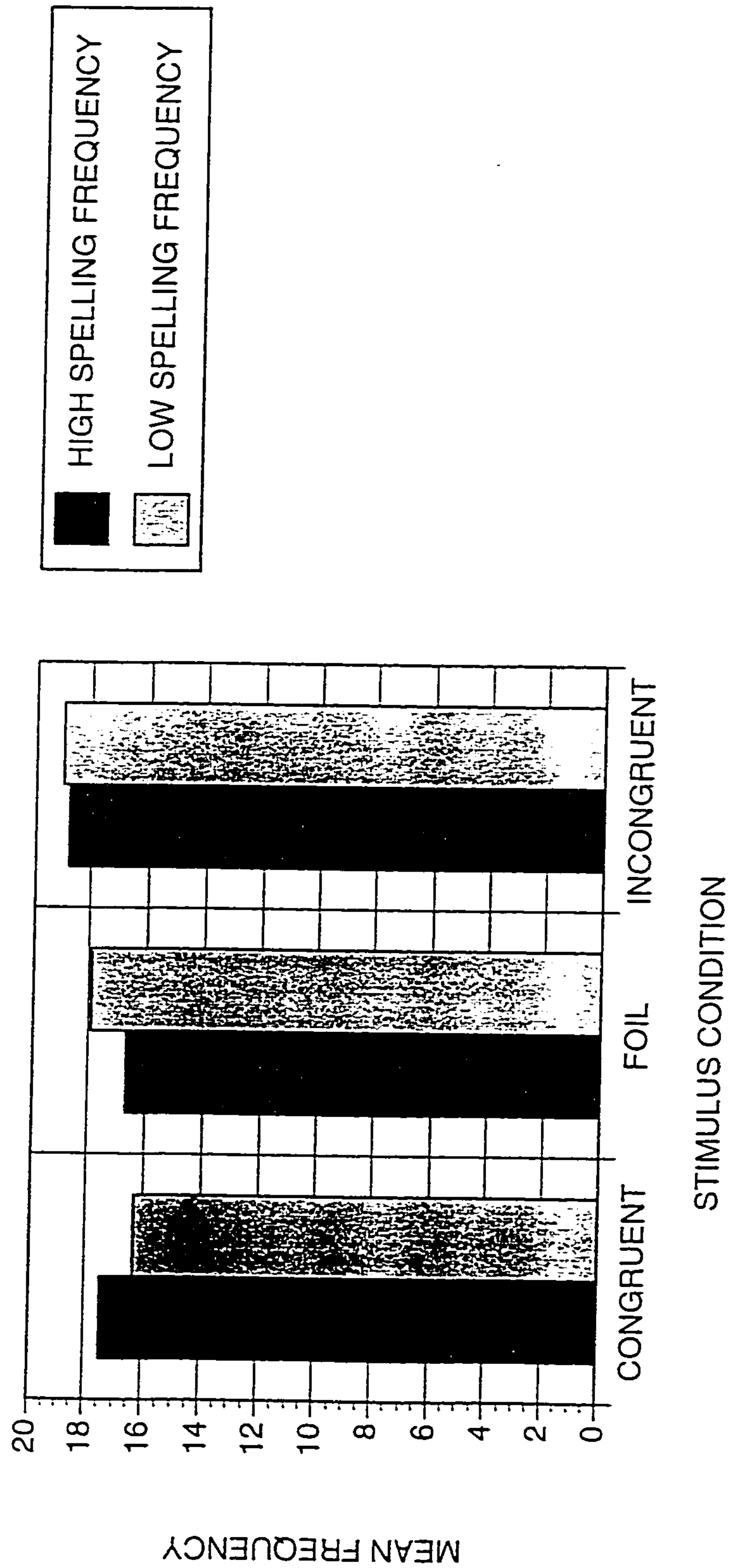
HIGH SPELLING FREQUENCY
LOW SPELLING FREQUENCY
MEAN FREQUENCY
20
18
16
14
12
10
8
6
4
2
0
CONGRUENT
FOIL
INCONGRUENT
STIMULUS CONDITION

Figure 3

Figure Caption

Figure 4. Graph depicting a significant interaction between Condition and Spelling Frequency factors for latency of correct responses made on the semantic judgement task in Experiment 1.

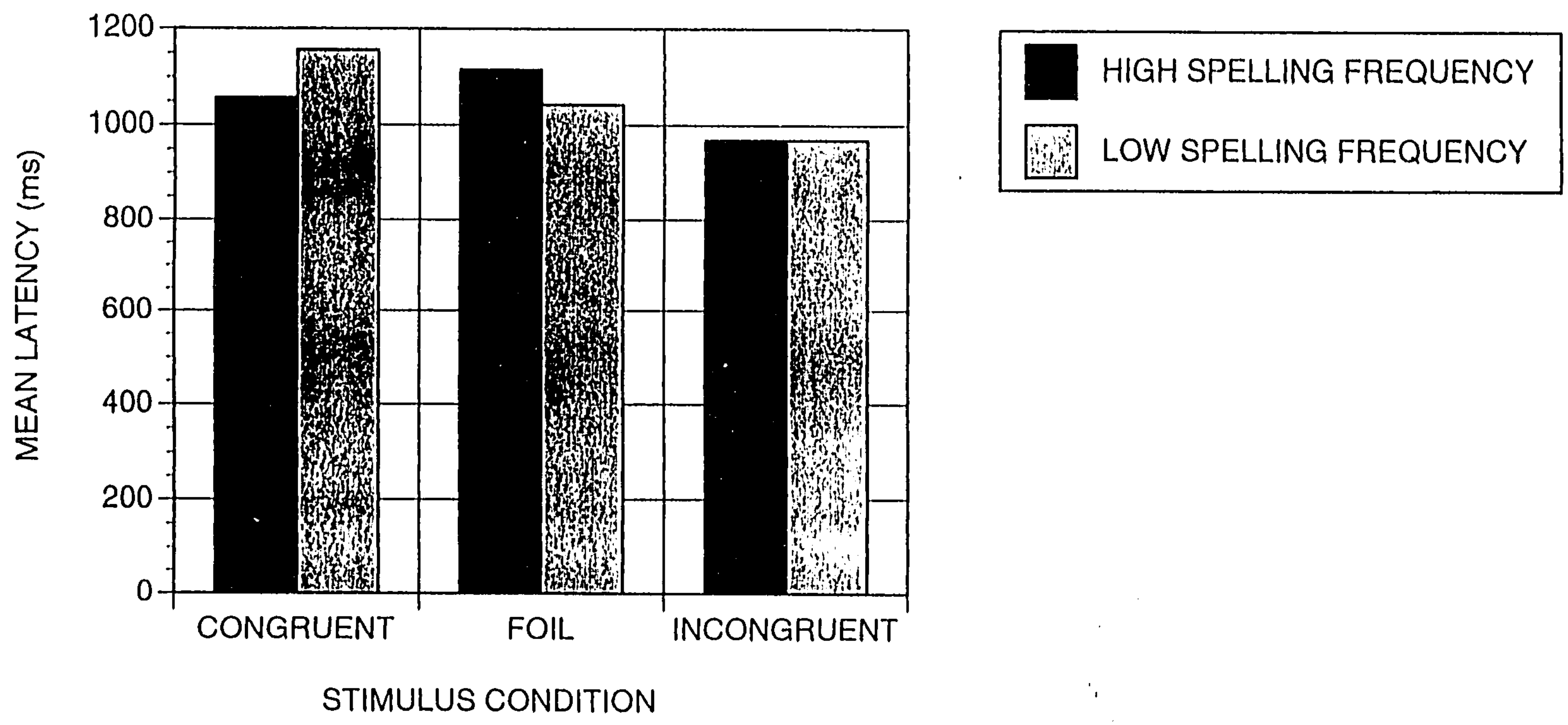
1200
1000
800
600
400
200
0
MEAN LATENCY (ms)
CONGRUENT
FOIL
INCONGRUENT
STIMULUS CONDITION
HIGH SPELLING FREQUENCY
LOW SPELLING FREQUENCY

Figure 4

words of the sentences were semantically congruous to the sentence context. The task used in this study was expected to force subjects to attend to orthographic codes and to reduce their reliance on phonological codes since the use of phonological codes would result in poor task performance. Previous research has demonstrated that manipulations in task requirements can be employed to discourage subjects from using phonological codes during word identification (Coltheart et al., 1991; 1994; Hawkins et al., 1977) from using phonological codes during reading since the use of these codes would result in poor task performance.

The results of this experiment suggested that the use of the behavioural task was efficacious. In contrast to Forbes (1993) the N400 did not respond differentially to the semantically incongruous terminal words of the sentences. That is, the phonologically unexpected terminal words in the INCONGRUENT condition produced N400 responses that did not differ significantly in amplitude from the N400 response produced by the FOIL condition. This finding indicates that the phonological codes associated with the homophone foils did not overshadow the effect of violating the semantic expectancy that was generated through semantic priming as had been observed by Forbes (1993).

The difference between this experiment and Forbes (1993) was the inclusion of the behavioural task. It is proposed that the use of the behavioural task caused subjects to focus on the orthographic codes associated with the homophone foils in order to facilitate task performance. Further evidence that the importance of phonological codes was diminished by the use of the semantic judgement task was obtained from the comparison of amplitudes between the CONGRUENT and FOIL conditions. The FOIL condition was associated with N400 amplitudes that were significantly larger than the amplitudes associated with the CONGRUENT condition. This finding indicates that the homophone foils were identified as semantically incongruous to the sentence context. That is, the phonological codes that were associated with the FOIL condition did not influence the N400 amplitude as had been observed in Forbes (1993).

Thus, the ERP data provide evidence that the use of the semantic judgement task diminished the importance of phonological codes during the sentence-reading task. Presumably, subjects based their decisions upon the orthographic representations that were associated with the terminal words of the sentences. This position was supported by the latency data obtained from the behavioural task. Inasmuch as the use of phonological codes would have made the decisions more complex it is reasonable to presume that this increased difficulty would be expressed in terms of longer latencies in the FOIL condition than in the INCONGRUENT condition. However, the latencies that were associated with these two stimulus conditions did not differ significantly from each other. This finding indicates that subjects did not require more time to form their decisions regarding semantic appropriateness regardless of whether the incongruous words were phonologically expected.

In contrast to this finding the accuracy data from the behavioural task suggests that phonological codes did influence the decision process. The accuracy level that was associated with the FOIL condition was significantly lower than that associated with the INCONGRUENT condition. If subjects relied solely upon orthographic representations then this difference in performance should not have been observed. Thus, the observation that subjects made more errors when deciding whether homophone foils were semantically appropriate suggests that the phonological codes associated with these words influenced their decisions. The lower accuracy level can not be attributed to a speed-accuracy trade-off insofar as the latencies associated with the FOIL condition did not differ from those associated with the INCONGRUENT condition.

The observation of longer latencies and lower levels of accuracy in the CONGRUENT condition compared to the INCONGRUENT condition was unexpected since the use of either phonological codes or orthographic codes should lead to the correct decision in both stimulus conditions. It is proposed that this effect was related to the high proportion of semantically incongruous sentences that were presented in the study. That is, the INCONGRUENT and

FOIL conditions, both of which presented semantically incongruous sentences, accounted for 60 percent of the total number of sentences.

In contrast, the sentences in the CONGRUENT condition accounted for only 30 percent of the total number of sentences. It is reasonable to believe that subjects were biased by the high proportion of anomalous sentences and had a tendency to respond to congruous terminal words as though they were semantically inappropriate. Such a bias would lead to a significantly lower level of accuracy in the CONGRUENT condition than in the INCONGRUENT condition. Further, subjects required more time to determine whether the terminal words in the CONGRUENT condition were semantically appropriate for the sentence context, as the data show.

The N270 component appeared to be sensitive to the orthographic representations of the terminal words. The results showed that the N270 component elicited by the INCONGRUENT condition was significantly larger than that elicited by the CONGRUENT and FOIL conditions which did not differ from each other. This finding is in contrast with Forbes (1993) who reported that the amplitude of the N270 component that was observed in the FOIL condition was not different from amplitudes associated with either the INCONGRUENT or CONGRUENT conditions.

However, the possibility was explored (based on a post hoc finding reported by Forbes, 1993) that a combination of homophone foils orthographically similar to their homophone partner, which are not likely to elicit a N270 response, with those that are orthographically dissimilar to their homophone partner, and are likely to elicit a N270 response, would lead to a reduction in the overall amplitude of the N270 response. As a result, it would be expected that the N270 amplitude observed in the FOIL condition would be smaller than that elicited by the INCONGRUENT condition but larger than amplitudes observed in the CONGRUENT condition.

A post hoc inspection of the waveforms compared the amplitudes associated with homophone foils that were orthographically similar to their homophone partner to those associated with homophone foils that were orthographically dissimilar to their homophone partner. In contrast to Forbes (1993) the N270 amplitudes that were elicited by the homophone foils did not differ according to their level of orthographic similarity to the expected terminal words. This finding raises the possibility that the N270 response may not be tied as closely to deviations in orthographic expectancy for the sentence-ending words as initially assumed.

Overall, the results of this experiment provide evidence to suggest that the use of the semantic judgement task diminished the role of the phonological factors that seemed to be important in Forbes (1993). This finding supports previous behavioural research which has demonstrated that changes in task requirements can influence whether phonological codes are influential in word identification processes (Coltheart et al., 1991; 1994). Another factor that has been investigated in behavioural research concerns the extent to which the phonological recoding effect can be attributed to the level of orthographic similarity that is shared between the homophones in a homophone pair. Van Orden (1987) has demonstrated that orthographically similar homophone foils are detected less frequently in a semantic categorization task than homophone foils that are orthographically dissimilar to their homophone partners.

Inasmuch as the N270 component did not respond differentially to orthographically similar and dissimilar homophone foils it is reasonable to suggest that these homophone foils were not easily distinguished from their homophone partners. Thus, it is conceivable that the evidence reported by Forbes (1993) supporting phonological recoding was actually attributable to the erroneous acceptance of the orthographic representations orthographically similar to appropriate terminal target words. The purpose of the next experiment was to investigate whether the evidence interpreted as support for phonological mediation could be explained by the orthographic similarity that exists between the semantically incongruous terminal words and the high probability terminal words for the sentences.

Chapter Four

Phonological and orthographic influences during silent reading of sentences involving homophones

Experiment 2

The results from Experiment 1 showed that the inclusion of a semantic judgement task reduced the importance of phonological factors during silent reading in comparison to the results reported by Forbes (1993). These findings are consistent with the behavioural research which has shown that changes in task requirements can diminish the influence of phonological codes during word identification (Coltheart et al., 1991; 1994). Another factor that has been shown to influence the evidence for phonological recoding is the level of orthographic similarity that is shared between the homophone foils and their homophone partners (Van Orden, 1987; Coltheart, et al., 1994).

Many homophone pairs share similar orthographic representations (e.g., bear/bare). It is possible that terminal words in the FOIL condition are more similar orthographically to the appropriate and correct terminal words than the words in the INCONGRUENT condition and hence their semantic inappropriateness is likely to be detected only if subjects are forced to attend to the orthographic representations by requiring them to perform a semantic judgement task as in Experiment 1. This makes it difficult to determine whether the variation in the amplitude of the N400 response observed by Forbes (1993) was due to phonological recoding or to a higher level of orthographic similarity between the semantically incongruous homophone foils and the appropriate terminal words.

While it is possible that the N400 component may be sensitive to the orthographic representations of sentence-ending words, consideration must be given also to the N270 component which we have noted previously appears to be directly sensitive to the level of orthographic similarity that homophone foils share with their homophone partners. Forbes

(1993) conducted a post hoc analysis of the N270 component and compared the N270 amplitudes elicited by orthographically similar and dissimilar homophone foils to each other. This analysis was carried out assuming that foils sharing the same initial letter and letter length as their homophone partner were considered to be orthographically similar. Those that violated these criteria were considered to be orthographically dissimilar. This basis for assessing orthographic similarities has been employed previously by Olson and Kausler (1971), and a number of other researchers (e.g., Daneman & Stainton, 1991; Marmurek, 1985).

The results of the post hoc analysis conducted by Forbes (1993) revealed that the amplitudes elicited by orthographically dissimilar homophone foils were significantly larger than those elicited by orthographically similar homophone foils. While this pattern was evident in Forbes (1993) it was not observed in Experiment 1 of the present series of studies. The difference between these studies may have been due the use of the semantic judgment task in Experiment 1. As indicated previously this task appears to have discouraged the use of phonological codes during word identification in order to facilitate performance on the semantic judgment task. Although the results of Forbes (1993) suggest that the N270 responds to deviations in orthographic expectancy, the findings must be interpreted cautiously since the level of orthographic similarity was examined post hoc rather than manipulated a priori.

The objective of the present study was to determine the extent to which orthographic similarity could have accounted for the variation in the amplitude of both the N400 and N270 responses. In this study, subjects read a series of unrelated sentences that had a high level of contextual constraint. Equal proportions of the sentence-ending words were congruous and incongruous to the sentence context. The congruous sentences were completed with the highly probable words (CONGRUENT). Three types of incongruous endings were presented. Anomalous endings were presented in equal proportions and were either 1) orthographically similar (OS condition) or 2) orthographically dissimilar (OD condition) to the highly probable terminal words for the sentences. The terminal words in these two stimulus conditions differed phonologically from the highly probable terminal words for the sentences. In contrast, the third type of anomalous stimuli were homophone foils (FOIL condition) that were phonologically identical to the semantically congruous terminal words.

The criteria used to determine the level of orthographic distinctiveness were the same as those used in the post hoc analyses conducted by Forbes (1993) and Experiment 1. Stimuli in the FOIL and OS conditions were classed as orthographically similar if they had the same initial letter and letter length as their partners (Olson & Kausler, 1971). All of the homophone pairs that were presented in the study satisfied both of these criteria. In contrast, the stimuli in the OD condition violated both of these criteria.

The proportion of homophone foils presented in the study was very low (12.5%). A low proportion of homophone foils was used to try to prevent subjects from developing a unique processing strategy favouring the use of phonological codes. Previous research has indicated that a high proportion of phonologically ambiguous stimuli encourages the use of phonologically based processing strategies in comparison to when a low proportion of these stimuli are used (e.g., McQuade, 1981; Martin, 1982; Jared & Seidenberg, 1991; Brysbaert & Praet, 1992). The use of a low proportion of homophone foils had the additional advantage of making the results of this study more readily comparable to a number of other studies which have also used low proportions of phonologically ambiguous stimuli (McQuade, 1981; Martin, 1982; Jared & Seidenberg, 1991; Brysbaert & Praet, 1992).

ERPs were recorded to the terminal words of the sentences. If phonological codes dominate the word identification process then variations in the amplitude of the N400 and N270 responses would be expected to occur in response to the manipulations of the terminal words of the sentences. Semantically incongruous terminal words in the OS and OD conditions were expected to elicit a N400 response because their phonological representations would identify them as anomalous with the sentence context. In contrast, a N400 response was not predicted to occur to the FOIL condition. It was assumed that in the FOIL condition the phonological codes would prevent the homophone foils from being identified as semantically incongruous to the sentence context.

If orthographic similarity is the dominant factor in word identification then a N400 response would not be elicited by either the FOIL or the OS conditions because words in both of these conditions satisfied the criteria for orthographic similarity to the expected words. In this case, the N400 response would occur only to sentence-ending words in the OD condition because these words violated the criteria for orthographic similarity for the high cloze probability words. The high cloze probability words presented in the CONGRUENT condition would not be expected to elicit a N400 response because they had been primed by the sentence context. It was assumed that larger N270 amplitudes would be observed to terminal words in the OD condition because they deviated from the orthographic expectancy that was generated by the sentence context whereas, the terminal words in the other conditions did not.

Method

Subjects

Twenty (males=10, females=10) student volunteers with a mean age of 19.9 years (range = 18-26 years) participated in this experiment. All subjects had normal or corrected-to-normal vision, were native English speakers and were dextral with a Laterality Quotient ranging from 66 to 100 as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were screened for reading comprehension (M=73.46, SD=10.45; range=56.25-87.88) using the Nelson-Denny Reading Comprehension test (Nelson & Denny, 1976). No subjects were excluded from the experiment on the basis of their score on the Nelson-Denny test. Subjects received course credit towards their first year psychology course or were paid $5 per hour for their participation. Informed consent was obtained prior to initiating the experiment.

Apparatus

Stimuli

A series of unrelated sentences with high contextual constraint were presented in this study (Shannon, 1948; Taylor, 1953). The target stimuli for the experiment were 30 homophone units that were obtained from standardized norms (Galbraith & Taschman, 1969; Olson & Kausler, 1971, Kreuz, 1987). As described previously, a homophone unit consisted of two words with identical pronunciations but different derivations, meanings and spellings (Kreuz, 1987). Each homophone within a homophone unit had high cloze probability for a highly contextually constrained sentence that was presented in the study. These sentences were used in Experiment 1 and by Forbes (1993). Pilot studies had been conducted to ensure that the sentences had a high level of contextual constraint and that each homophone had high cloze probability for a unique sentence in the stimulus set (See Appendix C for sentence stimuli).

The terminal words that were used to complete the sentences were either congruous or incongruous to the sentence context. The congruous sentences were completed with the high cloze probability homophones from the homophone pairs (CONGRUENT-HOMOPHONE). These sentence-ending stimuli had been primed by the high level of contextual constraint. They satisfied the semantic, orthographic and phonological expectancies that were generated by the sentence context.

In contrast, three types of semantically anomalous sentence-ending stimuli were presented in the FOIL, OS and OD conditions. The terminal words in the FOIL condition shared their phonological representations with the high cloze probability words. These words were also considered to be orthographically similar to the high cloze probability words because they shared the same initial letter and letter length with them. The OS condition also satisfied both of these orthographic criteria and were considered to be orthographically similar to the high cloze probability words. Unlike the FOIL condition the stimuli in the OS condition were phonologically different from the semantically appropriate terminal words. The terminal words in the OD condition violated both of the criteria for orthographic similarity and were phonologically different from the high cloze probability words of the sentences. See Table 3 for examples of sentences.

The two sentence contexts used with each of the homophone units were presented in the study. The terminal words from the four stimulus conditions that were used to complete the sentences were manipulated. This manipulation permitted all four stimulus conditions to be represented with each homophone unit. The terminal words representing each stimulus condition were used to complete the two sentences associated with each homophone pair in the experiment. Since there were only two sentences that were associated with each homophone pair only two of the four stimulus conditions could be presented to each subject for each homophone pair. In order to represent all four conditions throughout the experiment a counterbalance design was used.

A Latin Square design was used to counterbalance the types of terminal words that were used to complete the two sentences that were associated with each homophone unit. There were two constraints placed on the Latin Square design. First, only one sentence could be completed using either the high cloze probability word from the CONGRUENT-HOMOPHONE condition or a homophone foil from the FOIL condition. This constraint ensured that only one of the homophones from each homophone pair would be presented to each subject in the study. Second, the same terminal word from either the OS or OD conditions could not be used to complete both of the sentences associated with a homophone pair. This constraint reduced the number pairings that were required to satisfy the requirements of the counterbalance design. There is a limited number of orthographically similar homophone pairs that exist. In order to

Table 3

Experimental Design used in Experiment 2

Stimulus Conditions	Sentence Example	Number of Trials
Congruent Homophone	The planets circle the **sun**.	12
Foil	Ned has a daughter and a **son**.	12
Orthographically Similar (OS)	The ship went out to **sea**.	18
Orthographically Dissimilar (OD)	Jenny played volleyball on the sandy **beach**.	18
Filler Sentences		
Related Filler	Piano keys are white a black.	24
Unrelated Filler	The dog chased the cat up the tree.	12

Note: Equal proportions of semantically congruous and incongruous endings were presented in the experiment. Sentences in the Related Filler condition were presented only when the terminal words of these sentences was not being used as a OS or OD sentence completion. Unrelated Filler sentences were obtained from norms reported by Bloom and Fischler (1980). A total of 96 trials was presented in Experiment 2.

maximize the use of the homophone pairs within the counterbalance design it was necessary to impose these constraints. A total of ten orders were needed to satisfy the requirements of the counterbalance design. The order in which the stimuli were presented to the subjects was randomized.

The constraints of the counterbalance design resulted in the OS and OD conditions being presented to subjects more frequently than the FOIL and CONGRUENT-HOMOPHONE conditions were presented. The OS and OD conditions were each represented by 18.75 percent of the sentence-ending words whereas, the FOIL and CONGRUENT-HOMOPHONE conditions were each represented by 12.5 percent of the sentences. As mentioned previously, the low percentage of terminal words in the FOIL condition was desirable because it made the results of this study more comparable to those of previous studies which used a low proportion of phonologically ambiguous stimuli.

Additional congruous sentences were included so that the overall percentage of congruous and incongruous sentences was the same. Two types of congruous filler sentences were added to the stimulus set. First, sentence contexts for which the visual controls in the OS and OD conditions had high cloze probability were used as filler sentences and completed 25 percent of the total number of sentences that were presented in the study. These sentences were referred to as RELATED FILLERS because the terminal word were also used throughout the study as visual controls for the high cloze probability words of the sentences associated with the homophone units.

A pilot study (N=23) was conducted to ensure that these words had high cloze probability for high contextually constrained sentences. However, these filler sentences were only presented when the same terminal words were not being presented as the completions for the sentences associated with a homophone unit. When the sentences from the RELATED FILLERS condition could not be used because the terminal words were being used in the OS and

OD condition a second type of filler sentence was presented. These filler sentences were obtained from a set of sentence completion norms (Bloom & Fischler, 1980). The terminal words of these sentences were not used to complete any of the sentences that were associated with the homophone units. They were referred to as UNRELATED FILLERS and were used to complete 12.5 percent of the total number of sentences that were presented in the study.

Stimulus Presentation and Physiological Recording

The terminal words ranged in length from 3 to 8 letters (M=4.43; Mode=4; ninety-eight percent of words were between 3 and 6 letters in length). The mean visual angle subtended by the terminal words was 2.41 degrees (range=1.78-4.76 degrees). EEG recordings were collected using a bandpass of 0.01-100 Hz and were digitally filtered to a bandpass of 0.01 - 35 Hz. This bandpass was wider than the bandpass used in Experiment 1. Unlike the present study, Experiment 1, was a follow-up to Forbes (1993) and therefore used the same bandpass as the earlier experiment conducted by Forbes (1993). A bandpass of .01-35 Hz increased the likelihood of observing any late occurring positivities that varied in amplitude according to the stimulus conditions. All other aspects of stimulus presentation and ERP recording were identical to those of Experiment 1.

Data Analysis

The ERPs at each recording site for each individual were obtained by averaging the EEG activity to sentence-ending words. Each individual's ERPs were then averaged together to obtain grand average waveforms which reflected the general ERP pattern for the group in different stimulus conditions. The amplitude and latency for the individual averaged waveforms was scored and analyzed in the same manner as in Experiment 1. Orthogonal planned comparisons were used to investigate the predicted N270 and N400 amplitude differences amongst conditions. These predictions were based upon the findings from Experiment 1 and Forbes (1993). See Table 2 for the orthogonal comparisons that were used to address the hypotheses of Experiment 2.

Tukey tests were used to examine effects associated with topography for the same reason mentioned in Experiment 1.

Procedure

The presentation of the sentences was conducted using the same procedure that was used to present the sentences in Experiment 1. However, a behavioural task was not used in this experiment.

Results

CONGRUENT CONDITIONS

The amplitude and latency data that were obtained from the semantically congruous conditions were analyzed separately from semantically incongruous conditions in a preliminary analysis. The three semantically congruous conditions were the CONGRUENT-HOMOPHONE condition, the RELATED FILLER condition and the UNRELATED FILLER sentences. This analysis was conducted to determine whether the data from these conditions could be combined to represent the ERPs for semantically congruous sentences (Kuperman et al., 1995). Since the sentences in all three congruous conditions were completed using high cloze probability words they were not expected to produce different ERP patterns. However, if the conditions did produce different ERP patterns then combining their data could potentially distort the overall amplitude associated with congruous sentences. Consequently, the differences observed between the stimulus conditions may not be reflected accurately. Therefore, the ERP data associated with the N270 and N400 components were compared for the congruent conditions.

N270 Amplitude and Latency

No amplitude or latency differences were observed between the congruous conditions.

N400 Amplitude

The pattern of ERP findings revealed that the amplitude of the N400 response varied significantly across the three semantically congruous conditions, $F(2, 38) = 8.28$, $p=.0025$. The post hoc analysis showed that the amplitudes associated with the sentences in the UNRELATED FILLER condition (M=5.62 μV, SD=5.83) that were selected from Bloom and Fischler's norms (1980) were significantly less negative than the amplitudes associated with the CONGRUENT-HOMOPHONE (M=3.74 μV, SD=5.07) and RELATED FILLER (M=3.01 μV, SD=4.05) conditions which did not differ from each other. No other significant effects were observed in this preliminary analysis.

N400 Latency

No main effects or interactions involving latency data from the semantically congruous conditions were observed.

Since the terminal words in all three conditions had high cloze probability for the sentences with high contextual constraint the difference in N400 amplitude was not expected nor is there a clear explanation for it. For this reason, the data from the UNRELATED FILLER condition was excluded from further analyses. The data from the CONGRUENT-HOMOPHONE and RELATED FILLER conditions were collapsed to make a new condition that represented the typical response to congruous terminal words that had been primed by the sentence context. This new condition was referred to as the CONGRUENT condition.

CONGRUENT, OS, OD AND FOIL ANALYSIS

N270 Amplitude

Level of Orthographic Similarity

The amplitude data from the individual averaged waveforms was analyzed in two separate analyses (as above in Experiment 1). The first analysis included Condition (4 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix D Table D1). The results of this analysis showed that the N270 amplitudes varied across the stimulus conditions.

Three orthogonal planned comparisons were performed to address the a priori hypotheses that had been made. These comparisons investigated the predicted differences between the stimulus conditions. The first orthogonal comparison investigated the amplitude differences between the FOIL and CONGRUENT conditions. The results of this analysis showed that the amplitudes associated with these two conditions did not differ significantly from each other. This pattern of results was consistent with Forbes (1993) and showed that the N270 did not respond differentially to the congruous terminal words and the homophone foils. However, this finding was in contrast with the results of Experiment 1 which showed that the N270 responded differentially to these two stimulus conditions.

The second orthogonal comparison investigated whether the amplitudes that were associated with the FOIL condition differed significantly from those elicited by the OS condition. This analysis investigated whether the N270 responded differentially to these orthographically similar stimuli. The results of this analysis showed that the amplitudes produced by these conditions did not differ significantly from each other.

The third orthogonal planned comparison investigated the effect of orthographic similarity on the N270 component. The mean amplitudes elicited by the terminal words from the OS condition were compared to those elicited by the OD condition. As predicted, terminal words in the OS condition which did not violate the criteria for orthographic similarity produced significantly smaller amplitudes than terminal words in the OD condition which violated both of these criteria. This comparison supported the post hoc findings of Forbes (1993) and revealed that the N270 was sensitive to orthographic similarity (see Appendix D, Table D2 for means). No other significant effects were observed in this analysis. See Figure 5 for grand averages.

Topographical Distribution

The repeated measures ANOVA which included Condition and Site as factors did not reveal any significant effects involving Site. However, a separate analysis that was performed on

Figure Caption

Figure 5. Grand average waveforms at 15 sites for the CONGRUENT (dotted red line), FOIL (dashed green line), OS (black) and OD (solid blue line) stimulus conditions in Experiment 2.

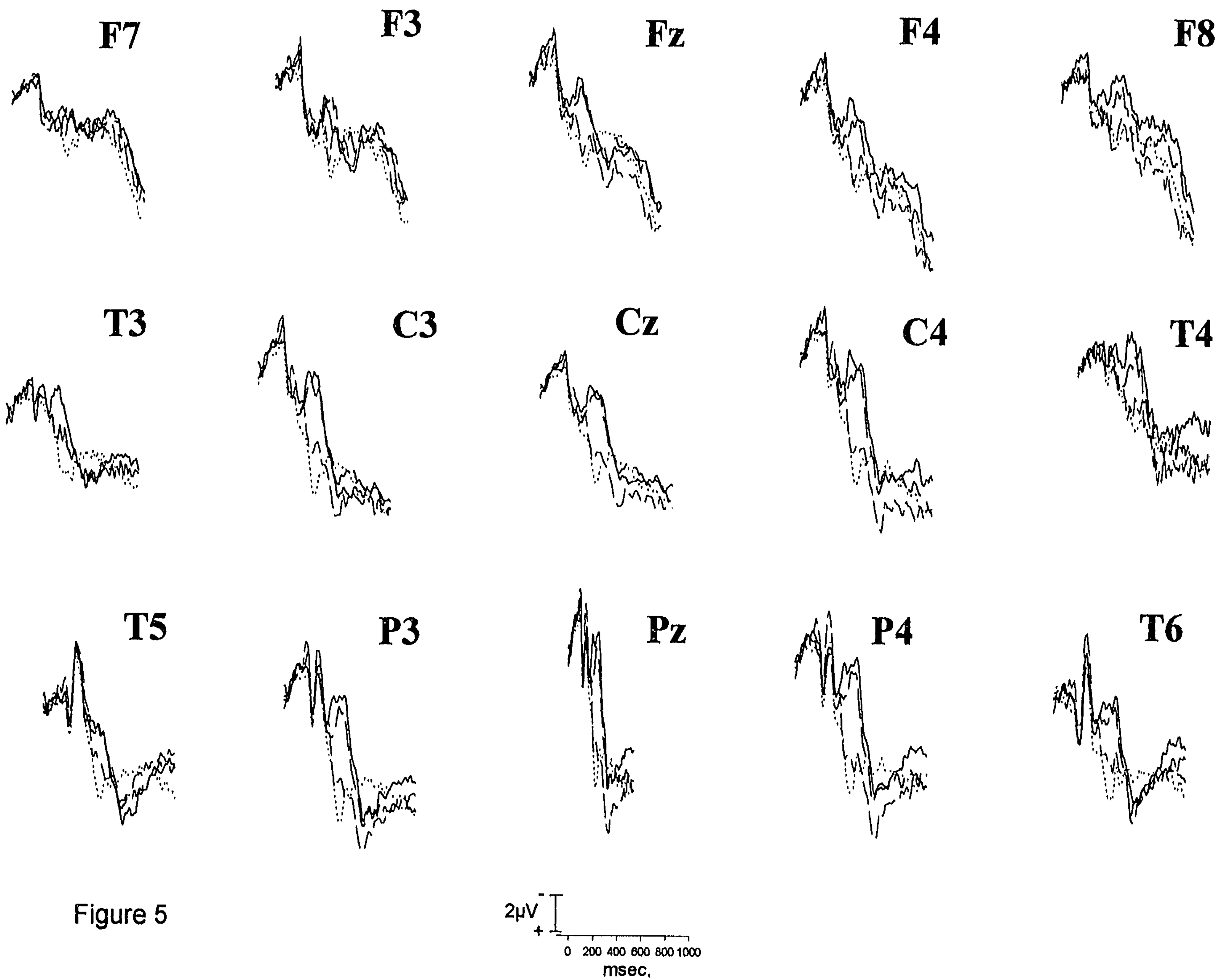
F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
2µV
0 200 400 600 800 1000
msec.

Figure 5

the data indicated that the topography of the N270 response varied across the scalp. This analysis included Condition (4 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix D Table D3). The results of the analysis revealed a main effect for Region indicating that the amplitudes varied significantly across the brain regions. A post hoc analysis of this main effect showed that the amplitudes observed over the temporal region were significantly larger than those observed over the central and parietal regions which did not differ from each other. The amplitudes associated with the frontal region did not differ from those observed in the other brain areas. Overall, these findings indicate that the N270 response was enhanced over the temporal brain areas (see Appendix D, Table D4 for means). No other significant main effects or interactions were observed.

N270 Latency

No significant main effects or interactions involving these factors were observed in either the first or second analysis of the latency data.

N400 Amplitude

Phonological Influences during Reading

The N400 amplitude data that was obtained from scoring the individual averaged waveforms were analyzed in two separate analyses. The first analysis included Condition (4 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix D Table D5). As predicted, the results of this analysis showed that the amplitudes varied across the stimulus conditions. Three orthogonal planned comparisons were performed to investigate the predicted difference in N400 amplitude amongst conditions.

The first orthogonal planned comparison investigated the amplitude differences observed between the OS and OD conditions. The terminal words of these conditions were orthographically similar and dissimilar to the high cloze probability word of the sentence, respectively. The results of this analysis revealed the amplitudes associated with these conditions did not differ from each other. This finding indicated that the N400 component was not sensitive to variations in orthographic similarity.

This result was supported by the results of the second planned comparison which investigated the amplitude differences observed by the FOIL and OS conditions. This analysis showed that significantly larger N400 amplitudes were elicited by the terminal words in the OS condition, than by the terminal words in the FOIL condition. The terminal words in these stimulus conditions satisfied the criteria for orthographic similarity but produced different ERP responses. In addition, the difference between the means associated with the OD and FOIL conditions was statistically significant inasmuch as the difference between these means was greater than that between the OS and FOIL conditions which were demonstrated to be significantly different from each other. Thus, the terminal words in FOIL condition produced different ERP patterns than the OS and OD conditions. This finding suggests that the phonological codes mediated the word identification process.

Further support for phonological mediation was obtained from the third planned comparison. This comparison investigated the difference between the CONGRUENT and FOIL conditions to determine whether the use of phonological codes produced a N400 response. The results of this analysis showed that the amplitudes associated with these stimulus conditions. were not different from each other (see Appendix D, Table D2 for means). This finding indicates that the terminal words in the FOIL condition produced similar neural responses as did those in the CONGRUENT condition. See Figure 5. Further support for the influence of phonological codes on the amplitude of the N400 response was obtained from a significant normalized interaction.

Topographical Distribution

A significant normalized interaction between the Condition and Site factors was observed in this analysis (Appendix D, Table D5). A post hoc analysis of this interaction revealed that the N400 response was enhanced over parietal and central sites in the OD condition and over the parietal sites in the OS conditions. The amplitudes observed over the midline parietal site (Pz) in the OD condition were significantly larger than those associated with the same site in the OS condition. In contrast, the amplitudes did not vary across the midline sites in the FOIL condition but did vary across these sites in the CONGRUENT condition. That is, the midline frontal site (Fz) in the CONGRUENT condition produced significantly larger amplitudes than did the central (Cz) and parietal (Pz) midline sites which did not differ from each other[1].

Differences in the topographical distribution of the N400 response were also observed between the stimulus conditions in the frontal and temporal brain areas. The OD condition elicited larger amplitudes over the anterior and posterior frontal sites in the right hemisphere than were observed over the same sites in the left hemisphere. This finding indicates that the N400 response was lateralized over the right hemisphere. In contrast, the amplitudes observed in the CONGRUENT condition were larger over the left anterior frontal site than over the right anterior frontal site. Finally, an anterior-posterior asymmetry was observed between the frontal sites in the right hemisphere. The amplitudes associated with the posterior frontal site in the OS, FOIL and CONGRUENT conditions were larger than those associated with the anterior frontal site. The same asymmetrical distribution was observed between the frontal sites in the left hemisphere that were elicited by the CONGRUENT condition.

The post hoc analysis of the interaction also revealed similar differences in the amplitudes of the N400 response elicited over the temporal sites. The amplitudes associated with the posterior temporal sites in the right hemisphere of the OS and OD conditions were significantly larger than those associated with the homologous sites in the left hemisphere. This hemispheric asymmetry was not observed over the anterior temporal sites for any of the conditions. An

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1 The importance of this finding is minimal insofar as the CONGRUENT condition does not result in N270 elicitation. This result only indicates that the point at which a negativity could be scored in the CONGRUENT condition tended to vary in amplitude across the electrode sites.

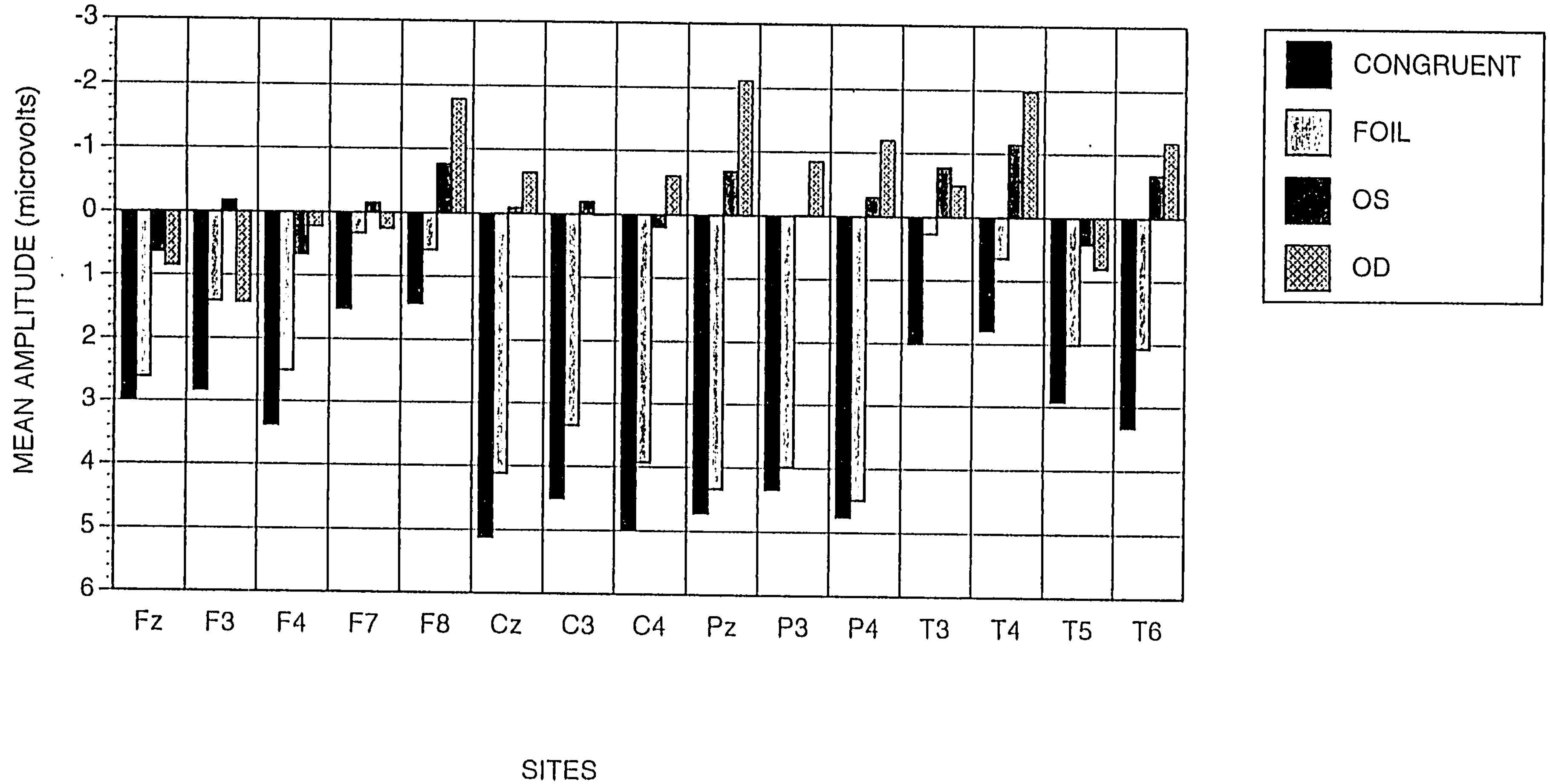
anterior-posterior asymmetry was observed over the left temporal sites in the OS, OD and FOIL conditions which showed larger amplitudes elicited at the anterior than posterior sites. The same anterior-posterior asymmetry was observed over the right temporal sites in the FOIL and CONGRUENT conditions. Overall, these findings suggest that the topographical distribution of the amplitudes elicited by the FOIL condition are, in general, more consistent with the distribution of the CONGRUENT condition than with either the OS or OD conditions. See Figure 6. This similarity in topography is consistent with the view that the phonological codes were used in the FOIL condition and influenced the distribution of the N400 response.

The second analysis included Condition (4 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix D Table D6). A main effect for the Condition factor was observed which was reported in the previous analysis. There were no significant main effects were observed for the Region or Hemisphere factors in this analysis. However, the results of this analysis did reveal a trend for Region. This trend suggested that the central and parietal regions were associated with larger amplitudes than were the frontal and temporal regions.

A significant normalized Condition X Region interaction was observed which post hoc analysis revealed was due to amplitudes in the OD condition being larger over the parietal and temporal areas than they were over the frontal areas. The OS condition also elicited amplitudes in the temporal condition that were significantly larger than those observed over the frontal regions. However, the amplitudes associated with the FOIL and CONGRUENT conditions showed a different pattern of response. In the FOIL condition, the amplitudes observed over the frontal and temporal regions, which did not differ from each other, were larger than those associated with both the central and parietal regions which also did not differ from each other.

Figure Caption

<u>Figure 6.</u> Graph depicting a significant interaction between Condition and Site factors for N400 amplitude data in Experiment 2.



MEAN AMPLITUDE (microvolts)
-3
-2
-1
0
1
2
3
4
5
6
Fz
F3
F4
F7
F8
Cz
C3
C4
Pz
P3
P4
T3
T4
T5
T6
SITES
CONGRUENT
FOIL
OS
OD

Figure 6

Similarly, the amplitudes observed over the parietal region in the CONGRUENT condition were significantly smaller than those observed over all of the other regions.

The topographical differences were also observed between the stimulus conditions. Amplitudes at the parietal region in the OS and OD conditions did not differ from each other but were significantly larger than those observed in the FOIL and CONGRUENT conditions (which also did not differ from each other). Further, central region amplitudes in the OD condition were larger than those observed in the same region for the FOIL condition. See Figure 7.

A significant normalized interaction was observed which involved the Condition and Hemisphere factors. A post hoc analysis of this interaction (all comparisons, $p<.05$) revealed that the amplitudes recorded over the right hemisphere were larger than those observed over the left hemisphere in the OS and OD conditions (this effect did not differ between these two conditions). Right hemisphere amplitudes in the OS and OD conditions were significantly larger than those observed in the same hemisphere in the FOIL and CONGRUENT conditions. Left hemisphere amplitudes in the OS and OD conditions were significantly larger than those in the right hemisphere for the CONGRUENT condition. Finally, the left hemisphere amplitudes elicited by the OD condition were significantly larger than the right hemisphere amplitudes that were observed in the FOIL condition. See Figure 8. These findings indicate that overall, the ERP pattern that was elicited in the FOIL condition was most consistent with the pattern elicited by the CONGRUENT condition.

N400 Latency

No main effects or interactions involving these factors were observed in either the first or second analysis of the latency data.

Discussion

In keeping with previous findings, the results of Experiment 2 demonstrate the sensitivity of the N400 component to terminal words of sentences that deviate semantically from those

Figure Caption

Figure 7. Graph depicting a significant interaction between Condition and Region factors for N400 amplitude data in Experiment 2.

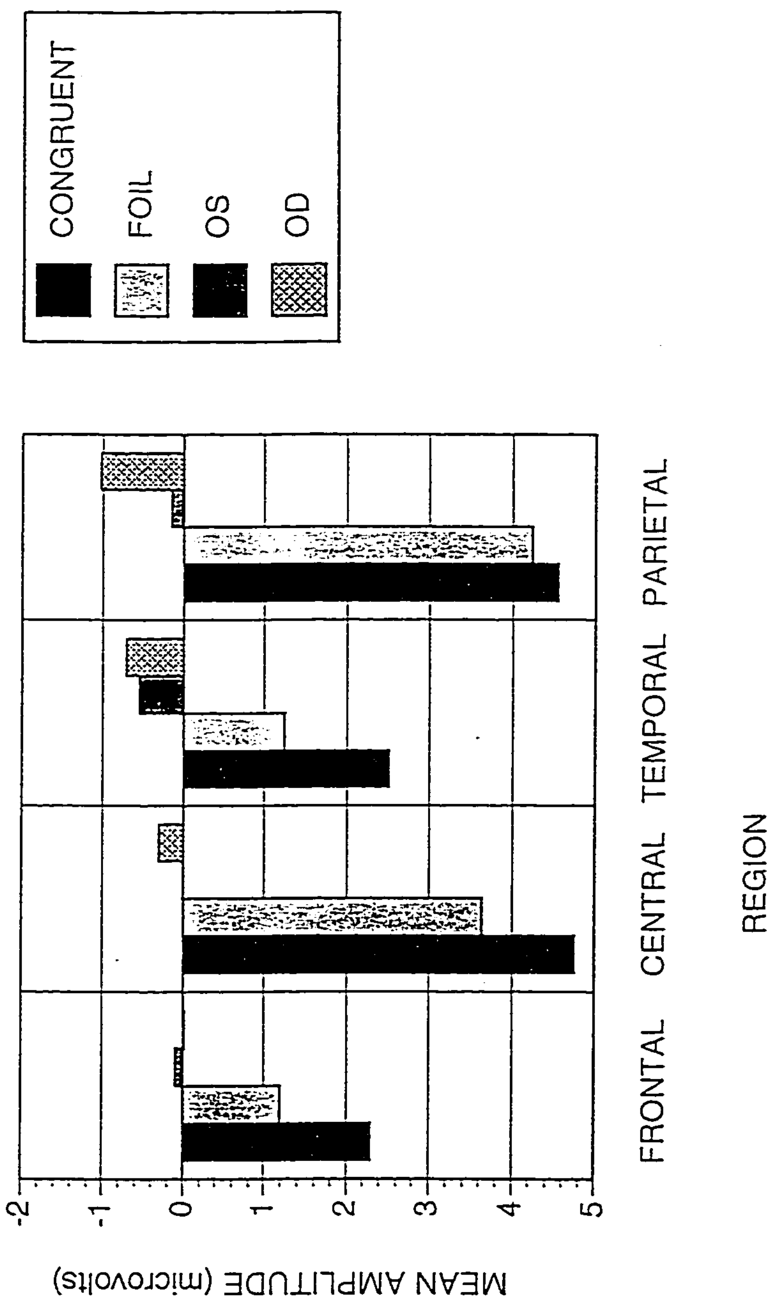

CONGRUENT
FOIL
OS
OD
MEAN AMPLITUDE (microvolts)
-2
-1
0
1
2
3
4
5
FRONTAL
CENTRAL
TEMPORAL
PARIETAL
REGION

Figure 7

Figure Caption

Figure 8. Graph depicting a significant interaction between Condition and Hemisphere factors for N400 amplitude data in Experiment 2.

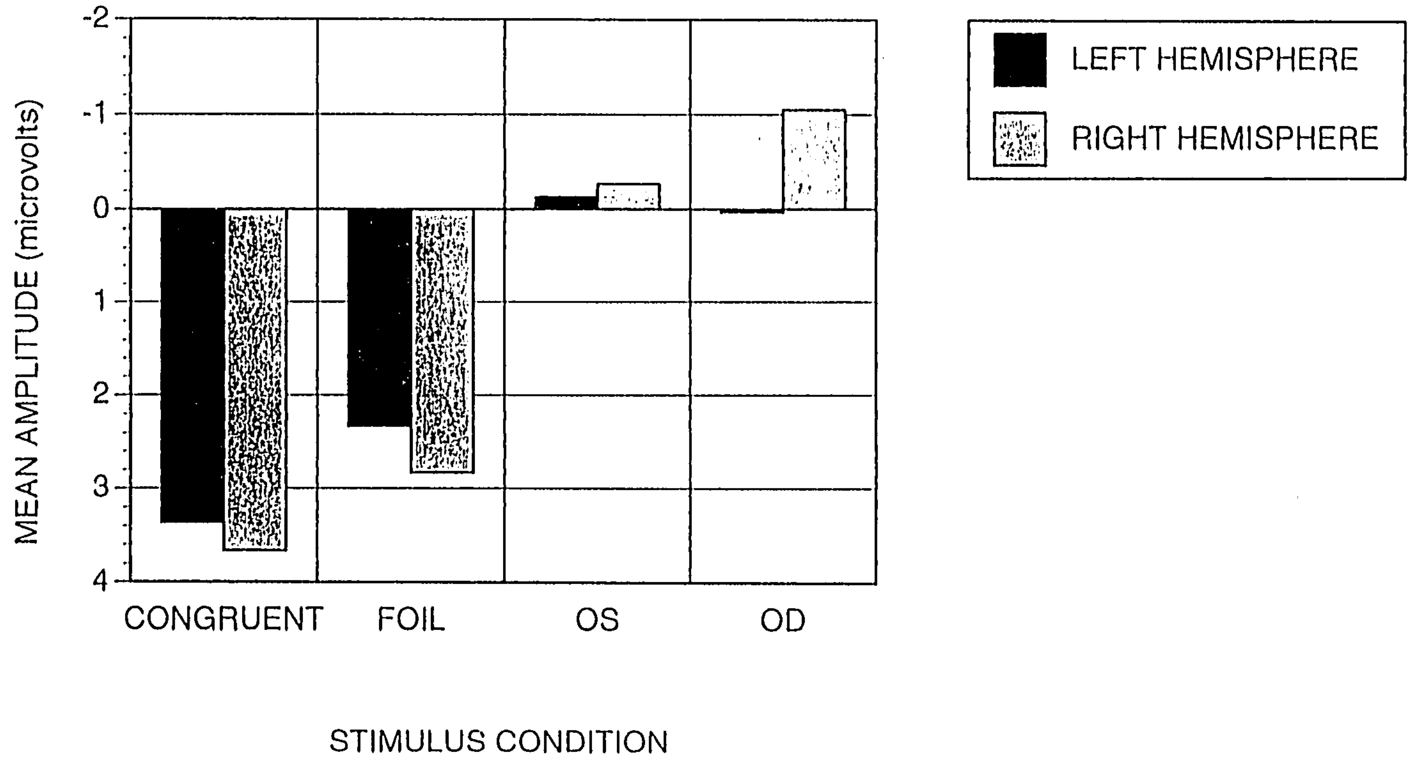

MEAN AMPLITUDE (microvolts)
-2
-1
0
1
2
3
4
CONGRUENT
FOIL
OS
OD
STIMULUS CONDITION
LEFT HEMISPHERE
RIGHT HEMISPHERE

Figure 8

primed by the sentence context (e.g., Connolly et al., 1995; Kutas & Van Petten, 1988). A N400 was observed when the sentence-ending words were semantically incongruent and did not share their phonological representation with the high cloze probability words. This was evident in both the OS condition, in which the terminal words were orthographically similar to the terminal words that were primed by the sentence context, and in the OD condition, in which the terminal words violated the criteria for orthographic similarity. As in Forbes (1993) there was a significant reduction in the amplitude of the N400 that was elicited in response to the sentence-ending words in the FOIL condition. These terminal words violated the semantic expectancy that was primed by the sentence context but met phonological expectations. These findings provide strong evidence that the reduced amplitude of the N400 response in the present study and in Forbes (1993) are attributable to phonological mediation.

The main objective of Experiment 2 was to determine whether the reduced amplitude of the N400 response in the FOIL condition of Forbes (1993) could be possibly attributed to uncontrolled orthographic similarities between phonetically appropriate, but semantically incorrect terminal words in the FOIL condition and the terminal words expected on the basis of the sentence context. Insofar as the results of this study showed that the N400 responses elicited by the terminal words in the OS and OD conditions did not differ from each other, these findings suggest that the N400 component is not sensitive to the orthographic similarity between homophones. While the N400 component was not sensitive to orthographic similarity, the N270 component was sensitive to the level of orthographic similarity that the incongruous words shared with the high cloze probability words.

The N270 response was expected to occur to terminal words in the OD condition since these words violated both of the criteria for orthographic similarity. In contrast, this component was not expected to be elicited by the FOIL, OS or CONGRUENT conditions which satisfied both of the criteria for orthographic similarity. The results of this study provide support for the post hoc analysis conducted by Forbes (1993). This post hoc analysis showed that significantly larger N270 amplitudes were elicited by homophone foils in the FOIL condition that were orthographically dissimilar to their homophone partner than by homophone foils that were considered to by orthographically similar to their partner. While the same post hoc analysis conducted in Experiment 1 did not show these results the most reasonable explanation for the difference between Experiment 1 and Forbes (1993) is that the use of the behavioural task discouraged subjects from using phonologically based processing strategies.

This position is supported by the present findings which showed that the N270 response was not sensitive to the semantic appropriateness of the terminal words but rather was sensitive to the orthographic similarity that the terminal words had to the high cloze probability words. The reduced amplitude of the N270 in the FOIL and OS conditions and the presence of the N400 in the OS condition suggests that the processes underlying the N270 component are different from those underlying the N400 component. Since the only difference between these incongruous conditions was that the terminal words in the FOIL condition shared their phonological representation with the high cloze probability words, the difference in the ERP patterns can be attributed to phonological mediation. The observation that the OS condition elicited a N400 response in the absence of the N270 response suggests that processes that reflect orthographic and phonological processes are separate and distinct from each other. That is, deviations in orthographic expectancy are reflected in the amplitude of the N270 response whereas, phonological codes influence the occurrence of the N400 response. These results provide evidence suggesting that these codes influence word identification at different stages of processing.

The results of Experiment 2 suggest that the N400 response is sensitive to semantic priming but does not appear to be sensitive to orthographic similarity during a sentence reading task. Although previous research has shown that non-rhyming words in a rhyming task elicited the N400 response this sensitivity to phonological codes has only been observed when the task instructions required subjects to direct their attention to the phonological representations of the stimuli (Sanquist et al., 1980; Polich et al., 1983; Kramer & Donchin, 1987). In contrast to the previous research the present study required subjects to read sentences for meaning. Therefore, the sentence reading task did not require subjects to direct their attention to the phonological representations of the sentence-ending words.

Research conducted by Kutas et al. (1984) has shown that the N400 responses elicited by words that are semantically unrelated to the words primed by the semantic context are significantly larger than the N400 responses elicited by words that are semantically related to the primed words. In addition, the N400 amplitudes associated with words that are semantically related to the primed words are significantly larger than the amplitudes associated with the primed words. These findings suggest that the amplitude of the N400 component reflects the degree to which semantic nodes are activated within the lexicon as a consequence of priming (Nigam et al., 1992). The indication that the N400 response reflects the degree of semantic activation in the lexicon raises the issue of whether an N400 response would be elicited by non-words, that are not represented within the lexicon, when they are used as sentence-ending stimuli. In addition, the results of Experiment 1 suggest that the importance of phonological codes during word identification can be influenced by the inclusion of a semantic judgement task. Other researchers have also shown that the inclusion of non-word stimuli in the stimulus set can affect the importance of phonological factors during visual word recognition (McNamara & Healy, 1988; Marmurek & Kwantes, 1996; Stone & Van Orden, 1993; Coltheart et al., 1991, 1994). The purpose of the next experiment was to investigate the effect of using non-word stimuli as sentence completions on both the magnitude of the phonological recoding effect and the amplitude of the N400 response.

Chapter Five

Evidence for phonological recoding in a sentence reading task involving homophones and pronounceable non-words

Experiment 3

The results of Experiments 1 and 2 are in keeping with previous findings that the N400 component is sensitive to semantic priming (e.g., Kutas & Van Petten, 1988; Connolly et al., 1995). The amplitude of the N400 response has been shown to vary according to the extent to which a particular word can be expected to complete a sentence. Congruous terminal words that have been primed by a high level of contextual constraint do not produce a N400 response. Presumably, words that are primed by the sentence context do not produce a N400 response because they are the anticipated sentence-ending words. In contrast, a large N400 response has been demonstrated to occur consistently to terminal words that are unexpected and semantically incongruous to the sentence context. The N400 response is clearly influenced by the extent to which a particular terminal word can be expected to complete the sentence.

A study conducted by Kutas and Hillyard (1980a) presented subjects with a series of unrelated sentences. Some of the terminal words of the sentences were semantically incongruous to the sentence context. The extent to which the terminal words were considered to deviate from the expected sentence-ending words was either moderate or strong. The results showed that the magnitude of the N400 response was influenced by the degree to which the terminal words were semantically unexpected. Terminal words that were considered to deviate strongly from the high cloze probability word produced larger N400 responses than did those considered to deviate moderately from the high cloze probability word. Further evidence that the amplitude of N400 response is sensitive to the degree to which the terminal words of sentences can be anticipated to occur was found in a further study by Kutas and Hillyard (1984).

Kutas and Hillyard (1984) manipulated the degree to which subjects anticipated the terminal words of sentences with high contextual constraint. All of the sentence-ending words in this experiment were semantically appropriate for the sentence context. However, the level of cloze probability of the terminal words was manipulated so that some sentence-ending words were more predictable than other sentence-ending words. The results showed that the amplitude of the N400 responses decreased as the level of cloze probability of the terminal words increased. The terminal words that had a low level of cloze probability, and were therefore less predictable, produced larger N400 responses than did terminal words that had a high level of cloze probability.

Van Petten and Kutas (1991) also investigated the amplitude of the N400 response to individual words in congruous sentences with high contextual constraint. The results showed that the size of the N400 amplitudes elicited by the individual words decreased across word position. This reduction in N400 amplitude was attributed to an increasing level of predictability for successive words in the sentences. Similar results concerning the size of the N400 response have been found by other researchers (e.g., Kutas et al., 1984; Koyama et al., 1992). Overall, these findings suggest that the N400 response is influenced by the degree to which a particular word can be expected (i.e., primes) to complete a sentence.

According to Morton (1969) semantic priming activates representations for words that are stored within a mental lexicon (i.e., mental dictionary). The degree to which these representations (referred to as semantic nodes) are activated is influenced by the predictability of the sentence-ending words. Terminal words that are made to be predictable by the sentence context are strongly activated within the mental lexicon. In contrast, the semantic nodes that are associated with less predictable terminal words are activated to a lesser extent. Presumably, the semantic nodes for words that are neither primed by nor semantically related to the high probability terminal words are not activated above their resting level of activation by the sentence context. Insofar as these unprimed words elicit the largest N400 responses, this suggests that the magnitude of the N400 response is influenced by the degree to which semantic nodes are activated by the preceding sentence context. This suggestion raises the question of the degree of influence non-word stimuli (which are not represented within the mental lexicon) would have on the N400 response if they were used as completions for highly contextually constrained sentences.

Since non-word stimuli have not been previously encountered by subjects they cannot be represented within the mental lexicon. ERP research has examined the effect of including non-word stimuli in a stimulus set. This research has explored the effect of repetition priming during word-pair paradigms both within and across modalities (Rugg et al., 1993), using different inter-item lags (Rugg & Nagy, 1989), same and different contexts (Rugg et al., 1994) and orthographically legal and illegal non-word stimuli (e.g., Rugg & Nagy, 1987). Overall, the results of these studies indicate that non-lexical stimuli were responded to in a similar fashion to real words in the lexicon. That is, the amplitude of the N400 response that was elicited by the first presentation of the non-word stimuli was larger than that elicited by subsequent presentations of the same non-word stimuli.

This pattern of ERP activation tends to be was also observed for repeated words. These findings suggest that variations in the amplitude of the N400 response can be observed through manipulations of both lexical and non-lexical stimuli. However, while lexical and non-lexical stimuli produce similar responses in repetition priming paradigms it is not clear that they will also produce similar responses in a semantic priming paradigm. The intent of Experiment 3 was to investigate the extent to which phonologically based strategies may be influenced by the inclusion of non-word stimuli in the stimulus set.

The objective was to determine whether the magnitude of the phonological recoding effect could be influenced by using non-word stimuli as completions for the sentences. A second objective was to determine whether non-words that are used as sentence-ending stimuli, and are not represented in the mental lexicon, elicit ERP responses that are similar to those elicited by semantically incongruous terminal words. To determine whether this was the case a sentence reading task was used and the sentence-ending stimuli were manipulated.

If the inclusion of the non-word stimuli diminishes the importance of phonological factors during reading in a manner similar to the semantic judgement task used in Experiment 1, then a N400 response should be evident in the FOIL condition. In the absence of phonological recoding, subjects will presumably use orthographic codes to obtain direct access to the lexicon. Thus, terminal words in the FOIL condition would be correctly identified as semantically incongruous, and a N400 response generated. The amplitude of this N400 response should not differ from that elicited by semantically incongruous terminal words that do not share their phonological representations with anticipated high probability words.

Incongruous words consistently produce a N400 response because they are not primed by the sentence context. Non-word stimuli not primed by the preceding sentence context are expected to produce a N400 response that should not differ from that produced by semantically incongruous terminal words. Highly probable terminal words that are semantically appropriate for the sentence context, should not, of course, produce a N400 response. Thus, the likelihood that the N400 response will be elicited by the sentence-ending stimuli in this experiment should be determined by the extent to which the stimuli are primed by the sentence context.

In contrast, the observation of the N270 response is expected to be sensitive to the level of orthographic similarity that the sentence-ending stimuli share with the anticipated terminal words. Strong evidence indicating that the N270 component is sensitive to orthographic similarity was obtained in Experiment 2 and by Forbes (1993). Congruous terminal words that are used to complete the sentences are not expected to produce a N270 response. As in Experiment 2, the FOIL condition is not expected to elicit a N270 component since homophone foils that are orthographically similar to their homophone partners will be used. Similarly, semantically incongruous words and the non-word stimuli that satisfied the criteria for orthographic similarity are not expected to elicit the N270 response. In contrast, orthographically dissimilar words and non-words are expected to produce N270 responses of similar amplitude because both types of stimuli violated the criteria for orthographic similarity.

Method

Subjects

Sixteen university educated individuals (females=8, males=8) with a mean age of 20.8 years (SD=3.83; range=18-31 years) participated in this experiment. All subjects had normal or corrected-to-normal vision, were native English speakers, and were dextral with a Laterality Quotient ranging from 42.86 to 100 as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were screened for reading comprehension (M=82.40, SD=7.14; range=69.23-95.00) using the Nelson-Denny Reading Comprehension test (Nelson & Denny, 1976). No subjects were excluded from participating on the basis of their Nelson-Denny score. Informed consent was obtained prior to initiating the experiment. Subjects received course credit towards their first year psychology course or were paid $5 per hour for their participation.

Apparatus

Stimuli

A series of unrelated sentences with high contextual constraint were presented in this study (Shannon, 1948; Taylor, 1953). The target stimuli that were used in the experiment were 32 homophone pairs that were obtained from standardized norms (Galbraith & Taschman, 1969; Olson & Kausler, 1971; Kreuz, 1987). As described previously, a homophone unit consisted of two words with identical pronunciations but different derivations, meanings and spellings (Kreuz, 1987). The homophone pairs that were used satisfied both of the criteria for orthographic similarity that was used in the previous experiments. That is, all homophones shared the same initial letter and letter number as their homophone partner (Olson & Kausler, 1971).

Each of the homophones within a homophone unit had high cloze probability for a highly contextually constrained sentence that was presented in the study. Thus, each homophone pair was associated with two different sentence contexts. Some of these sentences had been used in Experiments 1 and 2 and by Forbes (1993). The other sentences, which had not been used in the previous experiments, were tested in a separate pilot study in order to ensure they had a high level of contextual constraint and that the homophones had high cloze probability for the sentences.

The endings of the sentences that were associated with the homophone pairs were manipulated. These sentences were completed equally often by stimuli that made them either semantically congruous or incongruous. The congruous sentences were completed using the high cloze probability words (i.e., the semantically appropriate homophones) for the sentences (i.e., CONGRUOUS-HOMOPHONE condition). These high cloze probability words had been primed by the high level of contextual constraint and therefore they did not violate any of the orthographic, semantic or phonological expectancies that had been generated by the sentence context. In contrast, semantically incongruous stimuli were also used to complete these sentences which violated the expectancies that were generated by the sentence context (See Appendix E, Table E1 for sentences with homophones as high cloze probability words).

Stimuli that were used to complete the sentences anomalously were semantically inappropriate words and pronounceable non-words. The non-word stimuli were pronounceable and were not listed in the Oxford dictionary. The degree to which these stimuli (both words and non-words) were orthographically similar to the high cloze probability words of the sentences was manipulated. Stimuli were either orthographically similar or dissimilar from the expected terminal words. The incongruous sentence-ending words and the non-word stimuli that were considered to be orthographically similar to the high cloze probability words satisfied both of the criteria for orthographic similarity. These stimuli shared their initial letter and letter length with the high probability words for the sentences. Orthographically similar words were either phonologically identical to (i.e., homophone foils - FOIL condition) or phonologically different from (OS-WORD condition) the high cloze probability words for the sentences. None of the orthographically similar non-word stimuli shared their phonological representations with the high cloze probability words (OS-NONWORD). In contrast to the orthographically similar stimuli, the orthographically dissimilar sentence-ending words (OD-WORD) and pronounceable non-word stimuli (OD-NONWORD) violated both of the criteria for orthographic similarity. They were neither phonologically similar or orthographically similar to the high probability words (See Appendix E, Table E1 for orthographically similar and dissimilar words and Table E2 for non-word stimuli). See Table 4 for examples of sentences from the stimulus conditions.

Stimuli that represented each of these four stimulus conditions (OS-WORD, OD-WORD, OS-NONWORD and OD-NONWORD) were used to complete the sentences for which the homophones had high cloze probability. Both of the sentence contexts that were associated with each homophone pair were presented in the study. Since there were only two sentences associated with each homophone pair only two of the six stimulus conditions could be presented to each subject for each homophone pair. In order to represent all of the stimulus conditions throughout the experiment sufficiently a counterbalance design was used.

A Latin Square design was used to counterbalance the types of terminal words used to complete the two sentences that were associated with each homophone unit. There were two constraints placed on the Latin Square design. First, only one sentence could be completed using either the high cloze probability word from the CONGRUOUS-HOMOPHONE condition or a homophone foil from the FOIL condition. This constraint ensured that only one of the homophones from each homophone pair would be presented to each subject in the study.

Table 4

Experimental Design used in Experiment 3

Stimulus Conditions	Sentence Example	Number of Trials
Congruent Homophone	Tomorrow the ship will set **sail.**	16
Foil	Tomorrow the ship will set **sale.**	16
Orthographically Similar Word	Tomorrow the ship will set **soup.**	12
Orthographically Dissimilar Word	Tomorrow the ship will set **false.**	12
Orthographically Similar Non-Word	Tomorrow the ship will set **stob.**	12
Orthographically Dissimilar Non-Word	Tomorrow the ship will set **gorff.**	12
Filler Sentences		
Related Filler	Larry writes with his left hand.	48

Note: A total of 128 sentences were presented in Experiment 3.

Second, only one sentence associated with the homophone unit was completed using stimuli from one of the remaining four experimental conditions. The stimuli used to complete the second sentence represented either the OS-WORD, OD-WORD, OS-NONWORD or OD-NONWORD stimulus conditions.

This second constraint, which did not permit more than one sentence to be completed with stimuli from these four experimental conditions, reduced the number of counterbalance orders needed to balance the stimuli across the subjects. It was necessary to reduce the number of counterbalance orders in the design because only a limited number of orthographically similar homophone pairs exists and there were several conditions that needed to be balanced within the design. In order to maximize the use of the homophone pairs in the study it was necessary to impose this constraint. A total of sixteen orders were needed to satisfy the requirements of the counterbalance.

The constraints that were imposed upon the counterbalance design resulted in low proportions of the sentences being completed with stimuli from all of the experimental conditions. The sentences in the CONGRUOUS-HOMOPHONE and FOIL conditions accounted for 12.5 percent of the total number of sentences. The low percentage of terminal words in the FOIL condition was desirable because it made the results of this study more comparable to those of previous studies which used a low proportion of phonologically ambiguous stimuli (M^c^Quade, 1981; Jared & Seidenberg, 1991).

Additional sentences were included in the stimulus set in order to increase the number of sentences contained in the visual control conditions (i.e., OS-WORD, OD-WORD, OS-NONWORD and OD-NONWORD conditions); a necessary step in order obtain reliable ERP data that were representative of the stimulus manipulations. Sixteen sentences were included in this stimulus set. These sentences were not presented in any other stimulus conditions. The terminal words that had high cloze probability for these sentences were homophones from homophone units that were not used in the experiment. The inclusion of sentences that had high cloze probability words which were homophones was done so that they did not differ from the sentences that were associated with the homophone pairs that were manipulated in the study. That is, all sentences had high cloze probability words that were homophones and the level of orthographic similarity of the incongruous endings was manipulated using stimuli that represented the OS-WORD, OD-WORD, OS-NONWORD and OD-NONWORD conditions. These sentences were counterbalanced across the Latin Square design so that each subject received sixteen additional sentences which were completed equally often with stimuli from all four experimental conditions. The sentences in each of these stimulus conditions represented 9.4 percent of the total number of sentences that were presented in the study (See Appendix E, Table E3 for extra sentences that were added to these stimulus conditions).

In addition, semantically congruous sentences were included in the stimulus set so that there would be an equal number of congruous and incongruous sentences presented in the study. These congruous sentences were used previously in Experiments 1 and 2 and had high contextual constraint. The sentences in this condition were analogous to those in the RELATED FILLER condition used in Experiment 2. These congruous filler sentences accounted for 37.5 percent of the total number of sentences that were presented in the study. The terminal words that had high cloze probability for the sentences in this condition were also used as stimuli in the OS-WORD and OD-WORD conditions. However, these additional congruous sentences were only presented when the same terminal words were not presented in the OS-WORD and OD-WORD conditions. Overall, the sentences presented in the study ranged in length from 4 to fifteen words (M=8.06, SD=2.06; Mode=7; ninety-four percent of the sentences were between 5 and eleven letters in length).

Stimulus Presentation and Physiological Recording

The stimuli were presented in the same manner as in previous studies. The terminal words for the sentences ranged from 3 to 10 letters (M=4.56; Mode=4; ninety-seven percent of the words were between 3 and 6 letters in length) and the mean visual angle subtended by the terminal words was 2.95 degrees (range=1.78-5.95 degrees). The ERP recordings were obtained in the same manner as in previous studies.

Data Analysis

The ERPs at each recording site for each individual were obtained by averaging the EEG activity to sentence-ending words. Each individual's ERPs were then averaged together to obtain grand average waveforms which reflected the general ERP pattern for the group in different stimulus conditions. The amplitude and latency for the individual averaged waveforms was scored and analyzed in the same manner as in Experiments 1 and 2. Orthogonal planned comparisons were used to investigate the predicted amplitude differences between conditions. These predictions were based upon the findings from Experiments 1 and 2 and Forbes (1993). A Tukey post hoc test was used to investigate amplitude differences associated with a main effect for Site or a significant interaction between the Condition and Site factors. Orthogonal planned comparisons were not used to examine significant effects involving topography for the reason described earlier.

Procedure

The presentation of the sentences was conducted using the same procedure that was used to present the sentences in Experiments 1 and 2. No behavioural task was used in this experiment.

Results

CONGRUENT CONDITIONS

The amplitude and latency data that were obtained from the two semantically congruous conditions were analyzed separately from the data collected from semantically incongruous conditions in a preliminary analysis (Kuperman et al., 1995). The semantically congruous conditions included the CONGRUOUS-HOMOPHONE and the RELATED FILLER conditions. This analysis was conducted to determine whether the data from these conditions could be combined to represent the ERPs for semantically congruous sentences. Since the sentences in the two congruous conditions were completed using high cloze probability words they were not expected to produce different ERP patterns.

However, if the conditions did produce different ERP patterns then combining their data could potentially distort the overall amplitude associated with congruous sentences. In this case, the differences between the stimulus conditions may not be reflected accurately. Therefore, the ERP data associated with the N270 and N400 components were compared for the congruent conditions. The results of these preliminary analyses revealed that the amplitudes and latencies associated with the N270 and N400 components in the congruous conditions did not differ from each other (all F's < .01). Consequently, the data from these conditions were collapsed to form the CONGRUENT condition which represented the typical ERP response to the high cloze probability words for the sentences.

CONGRUENT, FOIL, OS-WORD, OD-WORD, OS-NONWORD AND OD-NONWORD ANALYSIS

N270 Amplitude

Orthographic Similarity and Lexical Status

The amplitude data from individual averaged waveforms was analyzed in three separate analyses. The first analysis included Condition (6 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix F Table F1). The results of this analysis showed that the N270 amplitudes varied across the stimulus conditions. Orthogonal planned comparisons were performed to address the predicted amplitude differences between the stimulus conditions. See Table 2. These comparisons investigated the sensitivity of the N270 response to the orthographic similarity of the stimuli used to complete the sentences.

The first analysis compared the amplitudes associated with the CONGRUENT condition with those associated with the FOIL condition. This analysis investigated whether there was a differential N270 response to the highly probably terminal words in the CONGRUENT condition and the terminal words in the FOIL condition which were orthographically similar (but not orthographically identical) to the expected sentence-ending stimuli. As in Experiment 2 and Forbes (1993), the results of this analysis showed that these conditions did not differ from each other in amplitude. This finding is in contrast with the results of Experiment 1 which showed that the N270 did respond differentially to these stimulus conditions. See Figure 9 for grand averages. This result indicated that the sentence-ending words in the FOIL condition produced similar responses to those produced by the highly probably terminal words in the CONGRUENT condition.

A planned comparison investigated the amplitude differences that were observed between the OS-WORD and OS-NONWORD stimulus conditions. The sentence-ending stimuli that were presented in the OS-WORD condition were English words whereas the sentence-ending stimuli presented in the OS-NONWORD condition were non-lexical stimuli. However, the stimuli in both of these stimulus conditions satisfied the criteria for orthographic similarity to the expected terminal words of the sentences. The results of this analysis showed that the amplitudes of the N270 responses elicited by these stimulus conditions were not different from each other. See Figure 9 for grand averages.

Inasmuch as the OS-WORD and OS-NONWORD conditions did not differ from each other these amplitude data were combined and compared with the FOIL condition. The stimuli in the OS-WORD, OS-NONWORD and FOIL conditions were orthographically similar to the highly probably words of the sentences. However, the stimuli in the FOIL condition was also

Figure Caption

Figure 9. Grand average waveforms at 15 sites for the CONGRUENT (solid green line), FOIL (dotted red line), OS-WORD (dot dot dashed pink line) and OS-NONWORD (long dashed black line) stimulus conditions.

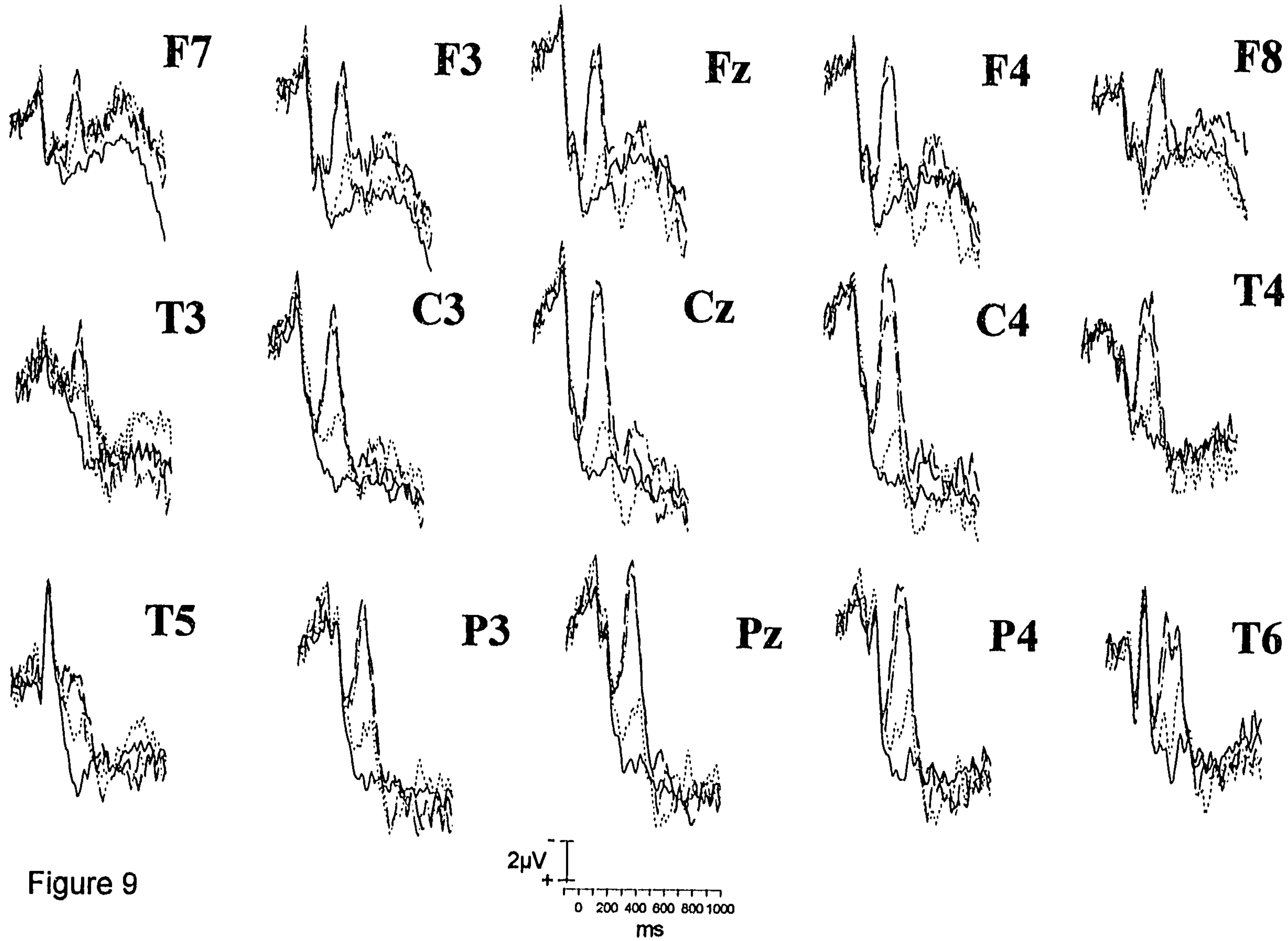

F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
2μV
-
+
0 200 400 600 800 1000
ms

Figure 9

phonologically identical to the expected terminal words whereas, the stimuli in the other two conditions were phonologically different from the expected terminal words. This analysis investigated whether the amplitude of the N270 response varied according to whether these orthographically similar stimuli were phonologically expected. The results of this analysis showed that the N270 amplitudes elicited by the phonologically expected homophone foils in the FOIL condition were significantly smaller than those elicited by the combination of stimuli in the OS-WORD and OS-NONWORD conditions. See Figure 9 for grand averages.

This result suggests that the N270 response was not sensitive to deviations in orthographic expectancy for the highly probable terminal words. This finding is supported by the results of the fourth planned comparison which investigated the amplitude differences between the OS-WORD and OD-WORD conditions. This comparison investigated whether the N270 was elicited by orthographically dissimilar stimuli. In contrast to the results of Experiment 2 these stimulus conditions did not differ from each other in terms of their N270 amplitudes. See Figure 10 for grand averages.

The final planned comparison investigated similar differences between the non-lexical stimuli. This analysis showed that the amplitudes associated with the OS-NONWORD and OD-NONWORD conditions were not different. The result of this analysis indicated that the orthographically similar and dissimilar words and nonwords that were phonologically unexpected produced similar N270 responses (see Appendix F, Table F2 for means). Thus, the elicitation of the N270 response did not appear to be tied to the degree to which orthographic codes associated with the incongruous stimuli deviated from those of the anticipated terminal words. See Figure 10 for grand averages.

A separate ANOVA was conducted to investigate the whether the lexical status of the sentence-ending stimuli interacted with the orthographic similarity of the sentence-ending stimuli that were phonologically unexpected. An ANOVA with repeated measures was performed

Figure Caption

Figure 10. Grand average waveforms at 15 sites for the OS-WORD (long dashed blue line), OD-WORD (solid blue line), OS-NONWORD (dot dashed red line), OD-NONWORD (dot dot dashed green line) stimulus conditions.

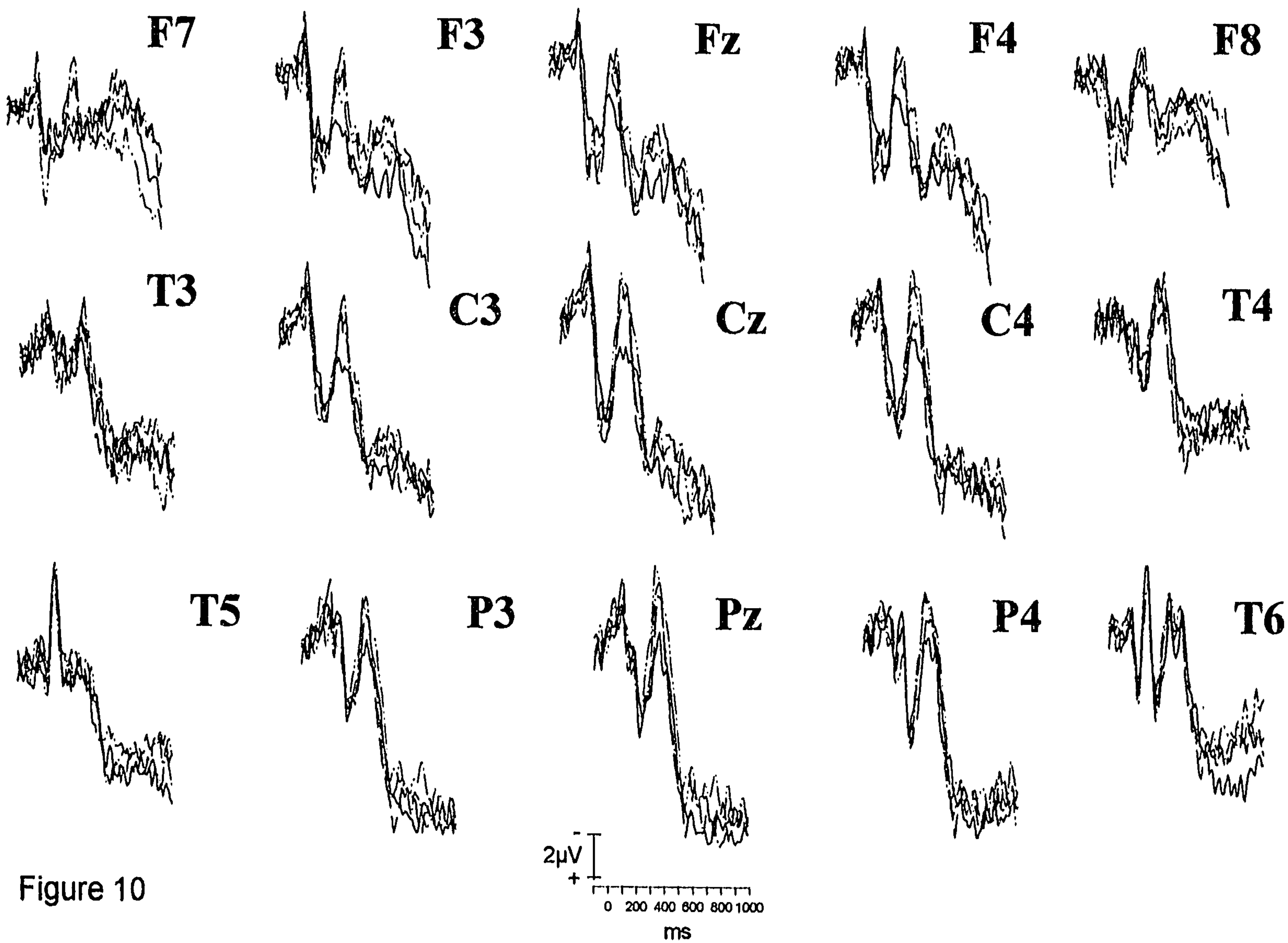

F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
2μV
-
+
0 200 400 600 800 1000
ms

Figure 10

which included Lexicality (2 levels), the Level of Orthographic Similarity (2 levels) and Site (15 levels) as factors. A Lexicality X Site interaction was observed which did not remain significant following the normalization procedure. No other significant main effects or interactions were observed in this analysis. Thus, the results of this analysis confirm the findings from the planned comparisons which did not show differences between the orthographically similar and dissimilar stimuli.

Topographical Distribution

The results of the ANOVA revealed that the amplitude of the N270 response varied reliably over the electrode sites. A post hoc analysis of this main effect showed that the amplitudes associated with the left anterior temporal site (T3) were significantly more negative than those associated with all parietal, central and most frontal sites but were not different from the amplitudes observed over the temporal sites or the left posterior frontal site (F7) (see Appendix F, Table F3 for means). Finally, a significant interaction was observed between the Condition and Site factors. However, this interaction did not remain significant following the normalization procedure indicating that the topographical distribution of the N270 response did not vary consistently with the stimulus conditions.

The final analysis of the N270 data included Condition (6 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix F Table F4). There was a significant main effect for Condition which was reported in the first analysis. The results of this analysis also revealed that the amplitudes of the N270 response varied across the brain regions. A post hoc analysis of this main effect showed that the temporal region was associated with significantly larger N270 responses than were the parietal and central regions. In addition, the amplitudes associated with the left hemisphere were significantly larger than those associated with the right hemisphere as indicated by the main effect for Hemisphere (see Appendix F Table F5 for means). This analysis also revealed that the Condition factor interacted with both the Region and Hemisphere factors. However, neither of these interactions remained significant following the normalization procedure. See Figures 9 and 10 for grand averages.

Latency

Three separate ANOVAs were performed on the N270 latency data. These analyses were 1) Condition X Site, 2) Condition X Region X Hemisphere and 3) Lexicality X Level of Orthographic Similarity X Site. A significant Lexicality X Site interaction was observed but did not remain significant following the normalization procedure. No significant main effects or interactions were observed in any of these analyses.

N400 Amplitude

Orthographic Similarity and Lexical Status

The amplitude data from individual averaged waveforms was analyzed in three separate analyses. The first analysis included Condition (6 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix F Table F6). The results of this analysis showed that the N400 amplitudes varied across the stimulus conditions. Orthogonal planned comparisons were performed to address the predicted amplitude differences between the stimulus conditions. See Table 2.

The first orthogonal comparison investigated the sensitivity of the N400 response to the orthographic similarity of the incongruous sentence-ending words that were phonologically unexpected. This analysis compared the amplitudes that were associated with the orthographically similar stimuli from the OS-WORD with the amplitudes that were associated with the OD-WORD. As in Experiment 2, the results of this analysis showed that the semantically incongruous terminal words elicited N400 responses that did not differ from each other. This finding suggests that the N400 response was not sensitive to the orthographic similarity that sentence-ending words shared with the highly probable terminal words for the sentences (see Appendix F, Table F2 for means).

A further indication that the N400 response is not tied to orthography was obtained from the second planned comparison. The N400 amplitudes that were associated with the OS-NONWORD conditions were compared with those elicited by the OD-NONWORD condition. This comparison was similar to the previous comparison inasmuch as the OS-NONWORD and OD-NONWORD stimuli varied in terms of the degree of orthographic similarity they shared with the expected terminal words of the sentences. As in the previous comparison, the stimuli in the OS-NONWORD and OD-NONWORD conditions elicited N400 amplitudes that did not differ from each other (see Appendix F, Table F2 for means).

The third planned comparison investigated the amplitude differences between the OS-WORD and OS-NONWORD conditions. The intent of this analysis was to determine whether the N400 responded differentially to orthographically similar stimuli depending on whether they were lexical or non-lexical. The results of this analysis showed that the amplitudes elicited by these stimulus conditions were not different. Consequently, the data from these stimulus conditions were combined for use in the next comparison (see Appendix F, Table F2 for means).

Phonological Recoding and the N400 Response

This analysis compared the N400 amplitudes that were elicited by stimuli that were orthographically similar to the expected terminal words but that varied in their phonological expectancy. The amplitudes that were associated with phonologically expected homophone foils in the FOIL condition were compared with those elicited by the phonologically unexpected stimuli from the OS-WORD and OS-NONWORD conditions. The results of this analysis showed that the FOIL condition produced significantly smaller N400 amplitudes than did the combination of the OS-WORD and OS-NONWORD conditions. This finding suggests that the N400 response was sensitive to the phonological representations of the sentence-ending stimuli.

However, the sensitivity of the N400 response to phonological codes appeared to be reduced in comparison to Experiment 2 and Forbes (1993). In contrast to these experiments which showed that the N400 amplitudes produced by the FOIL and CONGRUENT conditions not differ the present study showed that the FOIL condition was associated with N400 amplitudes that were significantly larger than those produced by the CONGRUENT condition. This difference in amplitude between these stimulus conditions was also observed in Experiment 1 and suggests that the incongruous homophone foils from the FOIL condition elicited a N400 response. Thus, the phonological codes that were associated with the homophone foils did not appear to be as influential in this experiment as in Experiment 2 and Forbes (1993) whereby these incongruous but phonologically expected stimuli did not elicit a N400 response.

A separate ANOVA was conducted to investigate the whether the lexical status of the sentence-ending stimuli interacted with the orthographic similarity of the sentence-ending stimuli that were phonologically unexpected. An ANOVA with repeated measures was performed which included Lexicality (2 levels), the Level of Orthographic Similarity (2 levels) and Site (15 levels) as factors. No significant main effects or interactions were observed in this analysis.

Topographical Distribution

Although a significant main effect for Condition was observed in this analysis there was not a significant main effect for Site. The absence of this main effect indicated that the size of the N400 amplitudes did not vary consistently across electrode sites. Finally, a significant interaction was observed between the Condition and Site factors. However, this interaction did not remain significant following the normalization procedure indicating that the differences in the topographical distribution of the N400 response observed at the electrode sites did not vary in a consistent manner across the stimulus conditions.

The final analysis of the N400 amplitude data included Condition (6 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix F Table F7). There was a significant main effect for Condition which was reported in the first analysis. There were no other significant main effects observed in the analysis indicating that the amplitudes did not vary consistently across brain regions or hemispheres. A significant interaction involving the Condition and Region factors was observed. However, this interaction did not remain significant following the normalization procedure. No other significant interactions were observed in this analysis of the amplitude data. See Figures 9 and 10 for grand averages.

Latency

The first analysis included Condition (6 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix F Table F8). The results of this analysis revealed that the latency of the N400 response varied across stimulus conditions. Since there were no a priori predictions concerning latency differences between the conditions a Tukey post hoc analysis was performed to investigate the source of this main effect. The results of this post hoc analysis revealed that the CONGRUENT condition was associated with latencies that were significantly longer than those associated with the OS-NONWORD, OD-NONWORD and OS-WORD conditions which were not different from each other (see Appendix F Table F9 for means)[2]. See Figures 9 and 10 for grand averages.

An ANOVA which included Lexicality X Level of Orthographic Similarity X Site was performed on the N400 latency data. No significant main effects or interactions were observed in this analysis.

Topographical Distribution

The repeated measures ANOVA involving Condition and Site as factors did not reveal a main effect for Site indicating that the latency of the N400 response did not differ across the electrode sites. A significant interaction between the Condition and Site factors was not observed

[2]The importance of this finding is minimal insofar as the CONGRUENT condition does not result in N400 elicitation. This result only indicates that the point at which a negativity could be scored in the CONGRUENT condition tended to be later than in stimulus conditions where the response actually occurred.

which indicated that the latencies associated with the electrode sites did not vary reliably with the stimulus conditions.

A separate analysis included Condition (6 levels), Region (4 levels) and Hemisphere (2) as factors in an ANOVA with repeated measures (see Appendix F Table F10). This analysis revealed a significant main effect for Condition which was reported in the first analysis. No other significant main effects were observed which indicated that the latency of the N400 response did not vary across brain regions or hemispheres.

A significant interaction was observed between the Condition and Hemisphere factors which remained significant following the normalization procedure. A Tukey post hoc analysis was performed to investigate the source of this interaction. The latencies associated with the left hemisphere in the OS-NONWORD condition were significantly shorter than those associated with both hemispheres for all of the stimulus conditions. The latencies of the N400 responses observed over the left and right hemispheres in the OS-NONWORD, OS-WORD and OD-NONWORD conditions did not differ from each other but were significantly shorter than the responses observed in both hemispheres by the OD-WORD, FOIL and CONGRUENT conditions. Finally, the OD-WORD condition was associated with significantly shorter N400 latencies in both hemispheres than was the FOIL condition which was associated with significantly shorter N400 latencies for both hemispheres than was the CONGRUENT condition. See Figure 11 for interaction. There were no other significant interactions observed between the Condition, Region and Hemisphere factors in this analysis.

Discussion

The results of Experiment 3 provide additional confirmation that the N400 component is sensitive to semantic priming during a sentence reading task (e.g., Van Petten & Kutas, 1991; Connolly et al., 1995). As seen in the previous experiments and Forbes (1993), a N400 response was elicited by incongruous terminal words that did not share their phonological representation

Figure Caption

Figure 11. Graph depicting a significant interaction between Condition and Hemisphere factors for N400 latency data in Experiment 3.

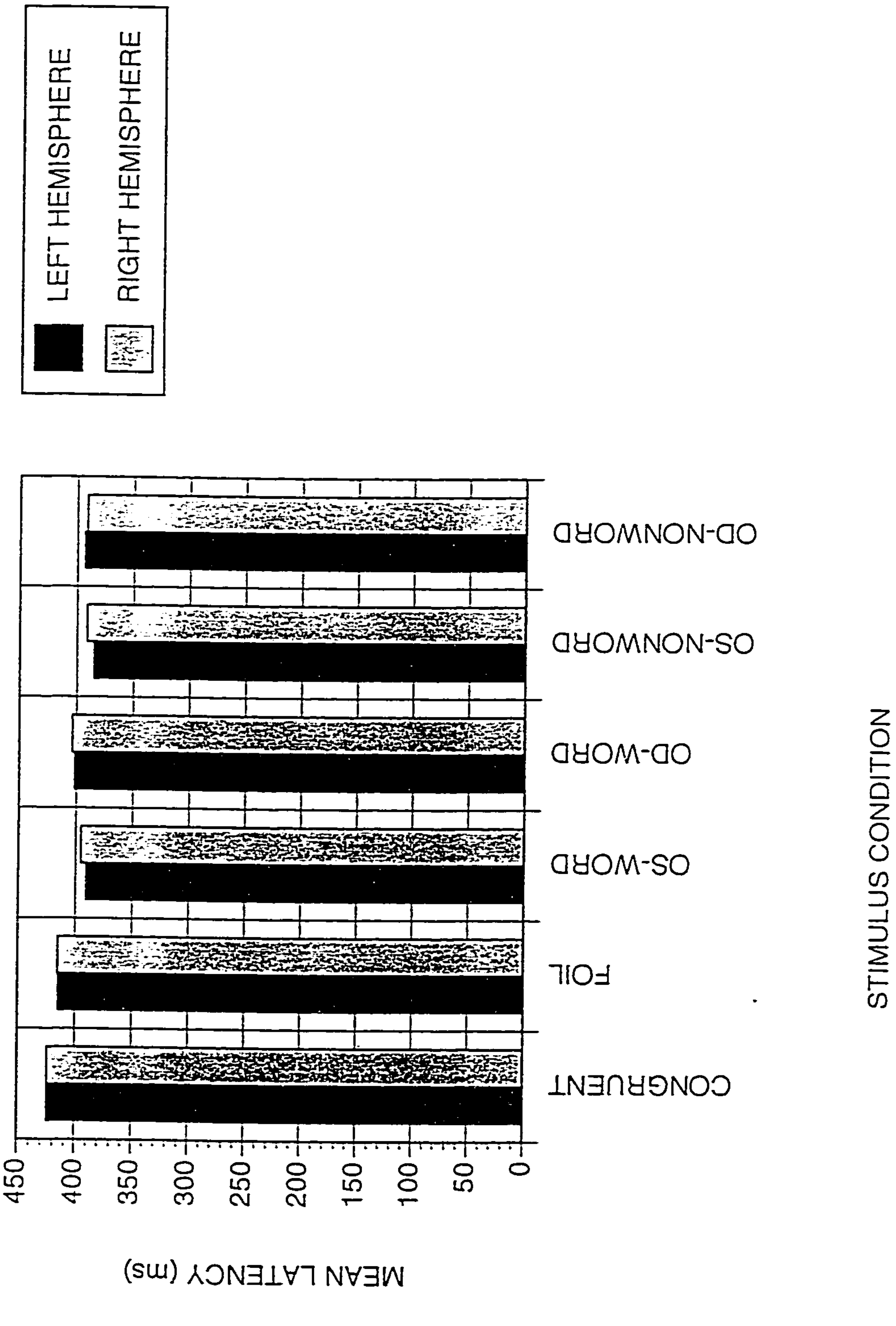

LEFT HEMISPHERE
RIGHT HEMISPHERE
MEAN LATENCY (ms)
450
400
350
300
250
200
150
100
50
0
CONGRUENT
FOIL
OS-WORD
OD-WORD
OS-NONWORD
OD-NONWORD
STIMULUS CONDITION

Figure 11

with the high cloze probability word. In addition, the non-word stimuli elicited N400 responses that did not differ in amplitude from those elicited by the phonologically unexpected incongruous terminal words. This effect was observed for both orthographically similar and dissimilar stimuli.

The main objective of this experiment was to determine whether the inclusion of non-word stimuli in the stimulus set would reduce the importance of phonological codes during reading. As seen in Experiment 2 and Forbes (1993) the amplitudes associated with the FOIL condition were significantly smaller than those that were associated with the phonologically unexpected incongruous stimuli. However, the results of Experiment 1 showed that the N400 amplitudes elicited by the FOIL condition did not differ from those elicited by the phonologically unexpected incongruous stimuli in the INCONGRUENT condition. This finding supports the findings from behavioural research which as shown that the use of phonological codes can be diminished by manipulating task requirements (Coltheart, 1991; 1994; Van Orden, 1987).

The results of this study provide additional support for this position. While the FOIL condition produced amplitudes that were smaller than those produced by phonologically unexpected incongruous stimuli, these amplitudes were larger than those elicited by the CONGRUENT condition. This difference in N400 amplitude suggests that the phonological factors that were important in Forbes (1993) and Experiment 2 in this series were diminished. Insofar as the previous experiments did not include non-word stimuli in the stimulus set it is proposed that the use of non-lexical stimuli in the present study was responsible for reducing the importance of the phonological factors.

The results of Experiment 2 and Forbes (1993) provide convincing evidence that the N270 component was sensitive to the degree to which the sentence-ending words were orthographically similar to the high probability words. In these previous experiments, a N270 response was elicited by terminal words that violated the criteria for orthographic similarity but was not elicited by terminal words that satisfied these criteria. In contrast to these previous experiments the N270 amplitudes associated with the FOIL condition in the present study were significantly smaller than those elicited by incongruous terminal words that were phonologically unexpected. This amplitude difference was observed regardless of whether the phonologically unexpected stimuli were orthographic similar (OS-WORD and OS-NONWORD conditions) or dissimilar (OD-WORD and OD-NONWORD conditions) to the highly probable terminal words.

These findings do not provide support for the position that the N270 is sensitive to the orthographic representations of the sentence-ending stimuli. Orthographically similar stimuli (OS-WORD and OS-NONWORD conditions) were not expected to elicit a N270 response because they satisfied the criteria for orthographic similarity as did the homophone foils in the FOIL condition. In contrast to Forbes (1993) and Experiment 2 this finding suggests that the N270 response is not tied to the level of orthographic similarity that is shared between the incongruous sentence-ending stimuli and the highly probable terminal words for the sentences.

Overall, these findings indicate that the phonological codes influenced the word identification process during the reading of sentences. The evidence of phonological recoding was measured in terms of the N400 amplitudes associated with the FOIL conditions. However, the importance of phonological codes during the sentence-reading task appears to have been influenced by the inclusion of non-word stimuli in the stimulus set. In keeping with this manipulation, another factor that has been suggested as capable of altering the use of phonologically based strategies is the inclusion of pseudohomophones in the stimulus set (Stone & Van Orden, 1993).

Homophones tend to share many letters in common with their homophone partner by virtue of their identical phonological representations. It is possible that the reduced N400 amplitude in Experiment 2 and Forbes (1993) that was associated with the phonologically expected stimuli in the FOIL condition compared with the phonologically unexpected stimuli was due to the increased level of orthographic similarity that homophone foils shared with their homophone partners. Pseudohomophones, similar to homophone foils, also share many letters in common with the semantically appropriate homophone from a homophone pair. The aim of the final experiment in this series was to investigate the extent to which phonological recoding occurs in a sentence-reading task when pseudohomophones are used as sentence completions.

Chapter Six

Phonological recoding during silent reading of sentences involving homophones and pseudohomophones

Experiment #4

The results of Experiment 3 demonstrate two important findings with regard to the use of non-word stimuli as completions of sentences with high contextual constraint. First, non-lexical stimuli elicit a N400 component that is similar in nature to that elicited by semantically incongruous and unexpected words. Second, the inclusion of non-words in the stimulus set attenuated the influence of the phonological factors that appeared to be important in Experiment 2 and in Forbes (1993). An important implication of these ERP data is that they support findings from behavioural research which has demonstrated that the importance of phonological codes can be reduced by manipulating task requirements or the type of stimuli included in the stimulus set (Stone & Van Orden, 1993; Jared & Seidenberg, 1991; McNamara & Healy, 1988).

Another factor that has been proposed to influence the phonological recoding effect is the inclusion of pseudofoils in the stimulus set. Pseudofoils are non-words that share their phonological representations with real words. Previous research using lexical decision tasks has indicated that these stimuli discourage the use of phonologically based strategies because the phonological codes do not facilitate task performance (Davelaar et al., 1978; McQuade, 1981). However, it is not clear whether the use of pseudofoils will influence the phonological recoding effect in a similar manner if they are used in a sentence-reading task.

The intent of the present study was to determine whether the inclusion of pseudofoils in the stimulus set would reduce the importance of phonological codes' influence during a sentence reading task in a manner similar to the reduction observed when a semantic judgement task (Experiment 1) and pronounceable non-word stimuli (Experiment 3) were included in the experiment. In addition, pseudofoils were used to investigate the extent to which the phonological recoding effect can be generalized. That is, homophone pairs are typically used to study the influence of phonological codes during the word identification process. It is possible that the evidence for phonological recoding is limited to the phonological representations that are associated with this special set of words. The present study examined whether the phonological codes that are associated with non-homophonic words can also mediate the processes involved in word identification.

This experiment used non-word stimuli (i.e., pseudofoils) that shared their phonology with either homophone pairs or non-homophonic words. It was hypothesized that if phonological codes that were associated with lexical and non-lexical stimuli influence word identification then a N400 would not be elicited by either pseudofoils or homophone foils. That is, the phonological representation of the pseudofoil, which is identical to the high cloze probability word of the sentence, would activate the appropriate lexical representation and therefore, not elicit a N400 response. If the phonological codes that were associated with non-lexical stimuli do not influence word identification then the pseudofoils should elicit a N400 response similar to that elicited by semantically incongruous and unexpected terminal words. This result is expected since pseudofoils are non-words and the previous study demonstrated that non-lexical stimuli elicit ERP patterns that are similar to those elicited by lexical items.

Pseudofoils that share their phonology with non-homophonic words were included in the stimulus set to examine the possibility that phonological recoding is unique to homophones. It is possible that the phonological recoding effect is limited to homophones and does not occur on a regular basis when reading non-homophonic words. This may occur because homophones, by definition, have two lexical representations and only one phonological representation. Thus, accessing the lexicon via the phonological representation may be more efficient for homophone pairs than for non-homophonic words. A N270 component was not expected to occur to any of the stimulus conditions used in this experiment since all semantically incongruous stimuli, lexical and non-lexical, were orthographically similar to the anticipated terminal words. That is, all incongruous stimuli shared the same initial letter and letter length with the expected terminal words (Olson & Kausler, 1971).

Finally, visual inspection of the individual averaged waveforms in Experiment 3 indicated that some subjects may have shown N400 responses to the FOIL condition that were comparable in size to the N400 responses that were observed to the incongruous stimuli that were phonologically unexpected (i.e., OS-WORD, OD-WORD, OS-NONWORD and OD-NONWORD). These larger N400 amplitudes that appeared to be elicited by the FOIL condition did not influence the overall grand average waveform since this effect was only observed in a few subjects. However, these observations raised the possibility that the N400 response may be elicited differentially in the FOIL condition depending upon the language skills of the subjects.

Individuals who perform well on tests of reading comprehension may still be more reliant upon a particular type of processing strategy. If subjects depend more heavily upon orthographically based strategies during word identification then it is conceivable that they would produce a large N400 response to the FOIL condition. A series of standardized neuropsychological tests were used to investigate this possibility. The subjects' abilities to use orthographic and phonological codes during word identification was assessed. The intent was to use performance on these tests to predict the likelihood that a N400 response would be elicited by the FOIL condition that was similar in amplitude to those elicited by the other semantically incongruous conditions.

Method

Subjects

Eighteen university students (females=9; males=9) with a mean age of 20.67 years (SD = 2.72; range = 18 - 29 years) participated in this experiment. All subjects had normal or corrected-to-normal vision, were native English speakers and were dextral with a Laterality Quotient ranging between 53.85 and 100 (mean=79.30, SD=16.85) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). The participants were screened for reading ability (M=77.50, SD=10.09; range=54.17-90.30) the Nelson-Denny Reading Comprehension test (Nelson & Denny, 1976). In addition, subscales from the Peabody Intellectual Achievement Test - Revised (PIAT-R), Wide Range Achievement Test - 3 (WRAT-3), the Woodcock-Johnson Reading Mastery Test - Revised and the Auditory Analysis Test were administered to each subject in a second test session. Subjects received course credit or payment in return for their participation. Informed consent was obtained prior to initiating each test session.

Apparatus

Stimuli

A series of unrelated sentences with high contextual constraint was presented in this study (Shannon, 1948; Taylor, 1953). Two types of target stimuli were used in this experiment: homophone pairs and non-homophonic words. A set of forty-two homophone pairs was obtained from standardized norms (Galbraith & Taschman, 1969; Olson & Kausler, 1971; Kreuz, 1987). As described previously, a homophone unit consisted of two words with identical pronunciations but different derivations, meanings and spellings (Kreuz, 1987). The homophone pairs that were used satisfied both of the criteria for orthographic similarity that was used in the previous experiments. That is, all homophones shared the same initial letter and letter length as their homophone partner (Olson & Kausler, 1971).

Each of the homophones within a homophone unit had high cloze probability for a highly contextually constrained sentence that was presented in the study (See Appendix G, Table G1 for sentences with homophones as high cloze probability words). Some of these sentences had been used in Experiment 1 through 3 and by Forbes (1993). Thus, each homophone pair was associated with two different sentence contexts. The second set of target stimuli consisted of forty-two non-homophonic words. Each of these words had high cloze probability as the terminal word for a unique sentence with high contextual constraint (See Appendix G, Table G2 for sentences with non-homophonic words as high cloze probability words). A pilot study was conducted using a separate pool of subjects (N=20) in order to ensure that the sentences which had not been used in previous experiments had high contextual constraint and that the words in this stimulus set had high cloze probability.

The endings for the sentences that were associated with the homophone pairs and the non-homophonic words in the stimulus set were manipulated. These sentences were completed in either a congruous or incongruous manner. An equal percentage of the sentences were congruous and incongruous. The congruous sentences were completed using the high cloze probability words. These high cloze probability words had been primed by the high level of contextual constraint and therefore they did not violate any of the orthographic, semantic or phonological expectancies that had been generated by the sentence context.

The sentences that were completed using the contextually appropriate homophone from a homophone pair were referred to as CONGRUOUS-HOMOPHONE and the sentences that were completed with the non-homophonic word that had high cloze probability were referred to as CONGRUOUS-NONHOMOPHONE. The terminal words in these conditions each completed 7.1% of the total number of sentences presented in the study. Additional congruous sentences were added to the design in order to increase the overall percentage of semantically appropriate sentences in the study to fifty percent. These highly contextually constrained sentences were used in previous experiments and were referred to as UNRELATED FILLER sentences. The high cloze probability words for these sentences were used as completions for the sentences in this condition. The remaining half of the sentences that were presented in the study were completed in an anomalous manner.

The stimuli that were used to complete the sentences anomalously were either semantically inappropriate words or they were pronounceable non-words. All of the incongruous endings were considered to be orthographically similar to the high cloze probability words for the sentences. That is, these endings satisfied both of the criteria for orthographic similarity (Olson & Kausler, 1971) because they had the same initial letter and letter length as the high cloze probability words. However, the phonological representations of the stimuli that were used to complete the sentences were manipulated.

The semantically incongruous stimuli either shared their phonological representations with the high cloze probability words or they did not. The semantically inappropriate words that were phonologically identical to the expected terminal words were homophone foils (FOIL condition). In addition, two types of non-word stimuli that shared their phonological representation with the high cloze probability words for the sentences were also used in the experiment. Since these stimuli were phonologically identical to the high cloze probability words they were referred to as pseudofoils. The pseudofoils shared their phonological representations with either the homophones or non-homophonic words that had high cloze probability for the sentence contexts that were presented in the study. These stimuli were referred to as PSEUDOFOIL-HOMOPHONE and PSEUDOFOIL-NONHOMOPHONE, respectively. All of the pseudofoils were normed on a separate pool of subjects (N=15) in order to ensure that subjects identified these non-words as having the same pronunciation as the intended homophone or non-homophonic stimuli (see Appendix G, Table G3 for pseudofoils for homophone pairs and Table G4 for pseudofoils for non-homophonic words).

Terminal words that did not share their phonological representation with the high cloze probability words were also presented. These sentence-ending words were orthographically similar to either the homophones or the non-homophonic words that had high cloze probability for the sentences. These stimulus conditions were referred to as OS-HOMOPHONE and OS-NONHOMOPHONE, respectively (See Appendix G, Tables G3 and G4 for words that are orthographically similar to homophone pairs and non-homophonic words, respectively). Overall, there were five stimulus conditions that completed sentences anomalously and there were three conditions that completed sentences appropriately. See Table 5 for examples of sentences from the stimulus conditions.

A Latin Square design was used in order to represent all of the stimulus conditions throughout the experiment. Two sentences were associated with each homophone unit and one sentence was associated with each of the non-homophonic words. The sentences that were associated with the homophone pairs were completed using stimuli from the CONGRUOUS-HOMOPHONE, FOIL, PSEUDOFOIL-HOMOPHONE and OS-HOMOPHONE conditions. The sentences associated with the non-homophonic words were completed with stimuli from the CONGRUOUS-NONHOMOPHONE, PSEUDOFOIL-NONHOMOPHONE and OS-NONHOMOPHONE conditions. The endings for sentences associated with the homophone pairs and the non-homophonic words were balanced separately from each other.

There were two constraints placed on the counterbalance design. First, one of the two sentences that were associated with a homophone pairs could be completed using stimuli from either the CONGRUOUS-HOMOPHONE, FOIL or PSEUDOFOIL-HOMOPHONE conditions. This constraint ensured that the phonological representation associated with each homophone pair was presented only once to each subject. Stimuli from each of these conditions completed 7.1 percent of the sentences in the study. The second constraint required that the remaining sentence that was associated with the homophone pair was completed with stimuli from the OS-HOMOPHONE condition. This constraint permitted the stimuli from this condition to be represented more frequently than the phonologically expected conditions. Consequently, 21.4 percent of the sentence-ending words were obtained from the OS-HOMOPHONE condition.

In contrast, the sentences that were associated with the non-homophonic words were completed equally often using stimuli from the CONGRUOUS-NONHOMOPHONE,

Table 5

Experimental Design used in Experiment 4

Stimulus Conditions	Sentence Example	Number of Trials
Homophonic Stimuli		
Congruent Homophone	He ordered a T-bone **steak**.	14
Foil	He ordered a T-bone **stake**.	14
Pseudofoil-Homophone	He ordered a T-bone **staik**.	14
Orthographically Similar-Homophone	He ordered a T-bone **store**.	42
Non-Homophonic Stimuli		
Congruent Non-homophone	The hockey player laced up his **skate**.	14
Pseudofoil-Nonhomophone	The hockey player laced up his **skait**.	14
Orthographically Similar-Nonhomophone	The hockey player laced up his **slime**.	14
Fillers		
Unrelated Fillers	The campers cooked dinner over an open fire.	70

Note: A total of 196 sentences was presented in Experiment 4.

PSEUDOFOIL-NONHOMOPHONE and OS-NONHOMOPHONE conditions. Each of these stimulus conditions was used to complete 7.1 percent of the sentences presented in the study. Overall, the counterbalance design presented an equal percentage of congruous and incongruous sentences and balanced the stimulus conditions across the sentences that were associated with the homophone pairs and the non-homophonic words. Six counterbalance orders were required to satisfy the requirements of the counterbalance design. The order of presentation for the sentences was randomized for each subject. Sentences ranged in length from 4 to 14 words (M=7.99, SD=1.80; Mode=8.0; 95.3% of the sentences were between 5 and 11 words in length).

Stimulus Presentation and Physiological Recording

The stimuli were presented in the same manner as in the previous experiments. The terminal words of the sentences ranged in length from 2 to 10 letters (M=4.58, SD=1.22; Mode=4; ninety-seven percent of the words were between 3 and 7 letters in length). The mean visual angle subtended by the terminal words was 2.95 degree (range=1.03-5.95 degrees). The electrophysiological data were recorded from the same sites using the same recording characteristics as were used in the previous experiments. The PIAT-R, WRAT-3, Woodcock-Johnson Mastery Test Revised and the Auditory Analysis tests were administered in a second testing session according to standard instructions that were provided in the test manuals.

Data Analysis

The ERPs at each recording site for each individual were obtained by averaging the EEG activity to sentence-ending words. Each individual's ERPs were then averaged together to obtain grand average waveforms which reflected the general ERP pattern for the group in different stimulus conditions. The amplitude and latency for the individual averaged waveforms was scored and analyzed in the same manner as in all of the preceding experiments. Orthogonal planned comparisons were used to investigate the predicted amplitude differences amongst conditions. See Table 2 for planned comparisons performed in Experiment 4. These predictions were based upon the findings from Experiments 1, 2 and 3 and Forbes (1993).

A Tukey post hoc test was used to investigate amplitude differences that were associated with a main effect for Site or a significant interaction between the Condition and Site factors. Again, orthogonal planned comparisons were not used to examine a main effect for Site for the reason given in previous experiments. Data collected from the PIAT-R, WRAT-3, Woodcock-Johnson Mastery Test Revised and the Auditory Analysis Test were scored according to standard instructions that were provided in the test manuals.[3]

Procedure

The procedures that were used for stimulus presentation and to obtain physiological recordings were identical to those used in previous experiments. A behavioural task was not used in this experiment. Upon completion of the first session a second test session was scheduled. During the second test session selected subscales from the PIAT-R, WRAT-3, Woodcock-Johnson Reading Mastery Test and the Auditory Analysis Test were administered (see Appendix H, Table H1 for test scores).

Results

CONGRUENT CONDITIONS

The N400 amplitude and latency data that were obtained from the three semantically congruous conditions were analyzed in a preliminary analysis. The semantically congruous conditions included the CONGRUOUS-HOMOPHONE, CONGRUOUS-NONHOMOPHONE and the UNRELATED FILLER conditions. This analysis was conducted to determine whether the data from these conditions could be combined to represent the ERPs for semantically

[3]Subjects performed at ceiling levels for all of the standardized tests and therefore there was little variability observed between the scores. Consequently, the test scores could not be used to predict the amplitude of the N400 responses that were elicited by the semantically incongruous sentence-ending stimuli. The mean test scores for the group of subjects are presented in Appendix H.

congruous sentences (Kuperman et al., 1995). Since the sentences in all three congruous conditions were completed using high cloze probability words they were not expected to produce different ERP patterns. However, if the conditions did produce different ERP patterns then combining their data could potentially distort the overall amplitude associated with congruous sentences. In this case, the differences between the stimulus conditions may not be reflected accurately. Therefore, the amplitude and latency data associated with the congruent conditions were compared.

The results of this preliminary analysis revealed that the N400 amplitudes that were associated with the congruent conditions differed significantly from each other. Insofar as the sentences in each of these conditions were completed with the high cloze probability word no a priori predictions regarding these conditions were made. Therefore, a Tukey post hoc analysis was performed to examine the source of the significant main effect. The results of this post hoc analysis revealed that the amplitudes associated with the CONGRUOUS-NONHOMOPHONE condition (M = -0.34 μV, SD = 5.17) were significantly larger than those associated with the CONGRUOUS-HOMOPHONE (M = 2.96 μV, SD = 5.77) and UNRELATED-FILLER (M = 2.64 μV, SD = 3.68) conditions which did not differ from each other. No differences in the latency of the N400 response were observed between the congruous stimulus conditions.

The reason for the amplitude differences between the congruous conditions was not clear[4]. The data associated with the CONGRUOUS-NONHOMOPHONE condition was

[4]The three semantically congruent conditions (CONGRUOUS-HOMOPHONE, CONGRUOUS-NONHOMOPHONE and UNRELATED-FILLER) were included with the FOIL, PSEUDOFOIL-HOMOPHONE, PSEUDOFOIL-NONHOMOPHONE, OS-HOMOPHONE and OS-NONHOMOPHONE as separate stimulus conditions in an ANOVA with repeated measures. The overall results of this analysis did not differ from the results of analysis reported in the text in which the CONGRUENT-HOMOPHONE and UNRELATED-FILLER conditions were collapsed to form the CONGRUENT condition and the CONGRUENT-NONHOMOPHONE condition was excluded. Further, the identical sentences were presented in all of the preceding experiments and Forbes (1993) and they did not produce different N400 amplitudes than sentences completed with the semantically appropriate homophones. Thus, the reason for the difference in N400 amplitude between the

excluded from further analyses so that it would not distort the typical response that elicited by semantically appropriate terminal words. Therefore, the new CONGRUENT condition which represented the typical response to semantically appropriate terminal words was made by collapsing across the data from the CONGRUOUS-HOMOPHONE and UNRELATED-FILLER conditions.

CONGRUENT, FOIL, PSEUDOFOIL-HOMOPHONE, PSEUDOFOIL-NONHOMOPHONE, OS-HOMOPHONE AND OS-NONHOMOPHONE ANALYSIS

N400 Amplitude

Phonological Influences during Reading

The amplitude data from the individual averaged waveforms was analyzed in two separate analyses. The first analysis included Condition (6 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix I, Table I1). The results of this analysis showed that the N400 amplitudes varied reliably across the stimulus conditions. Orthogonal planned comparisons were performed to address the predicted amplitude differences amongst the stimulus conditions. See Table 2.

The first orthogonal comparison investigated the differences in amplitude that were observed between the CONGRUENT and FOIL conditions. As in Experiments 1 and 3 this analysis revealed that the FOIL condition elicited significantly larger N400 amplitudes than did the CONGRUENT condition. This finding indicated that the N400 response was different to the homophone foils and the semantically appropriate terminal words even though the homophone foils were phonologically expected. Since the difference in amplitude between the CONGRUENT and OS-NONHOMOPHONE conditions and the CONGRUENT and OS-

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CONGRUENT-NONHOMOPHONE condition and the other semantically congruous conditions (CONGRUOUS-HOMOPHONE and UNRELATED-FILLER conditions) is not clear. In order to simplify the interpretation of the results the N400 data associated with the CONGRUOUS-NONHOMOPHONE condition were excluded from further analyses and were not reported.

HOMOPHONE conditions was larger than that observed between the CONGRUENT and FOIL conditions, which were significantly different from each other, this analysis also revealed that the CONGRUENT condition produced significantly smaller amplitudes than both the OS-HOMOPHONE and OS-NONHOMOPHONE conditions. This finding was observed in previous experiments and indicated that the N400 response was sensitive to semantic priming (see Appendix I, Table I2 for means). See Figure 12 for grand averages.

The second planned comparison investigated the sensitivity of the N400 response to semantically incongruous terminal words that were orthographically similar to homophone pairs or to non-homophonic words. This analysis compared the amplitude differences that were observed between the OS-HOMOPHONE and OS-NONHOMOPHONE conditions. The results showed that these conditions did not differ significantly in amplitude from each other.. This finding indicated that the N400 responded similarly to phonologically unexpected and semantically incongruous words that were visually similar to homophone pairs or non-homophonic words (see Appendix I, TableI2 for means). See Figure 12 for grand averages.

The third planned comparison investigated the sensitivity of the N400 response to phonological codes during reading. The amplitudes associated with the OS-HOMOPHONE and FOIL conditions were compared. The stimuli in both of these conditions satisfied criteria for orthographic similarity to the same highly probable terminal word. However, the sentence-ending words in the FOIL condition were phonologically expected whereas, the terminal words in the OS-HOMOPHONE condition were phonologically unexpected. As in Experiments 2 and 3 and Forbes (1993) the results of this analysis revealed that the terminal words in the FOIL condition elicited amplitudes that were significantly smaller than the amplitudes elicited by the OS-HOMOPHONE condition. This result is in contrast to the findings of Experiment 1 which showed that the N400 amplitudes elicited by the INCONGRUENT and FOIL conditions did not differ from each other. Inasmuch as the incongruous terminal words in these stimulus conditions

Figure Caption

Figure 12. Grand average waveforms at 15 sites for the CONGRUENT (solid green line), FOIL (dotted red line), OS-HOMOPHONE (dot dot dashed blue line) and OS-NONHOMOPHONE (long dashed pink line) stimulus conditions.

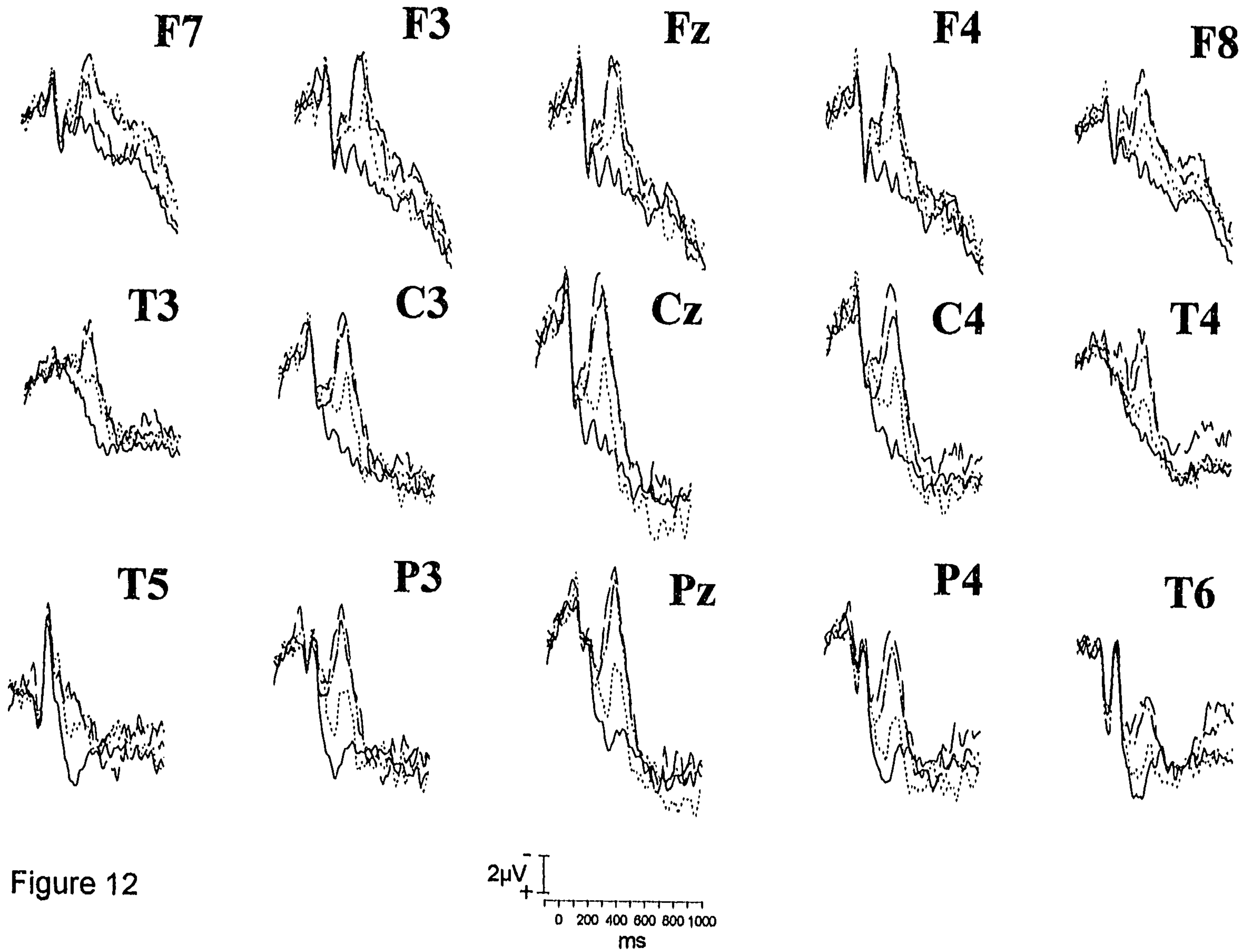
F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
2μV
-
+
0 200 400 600 800 1000
ms

Figure 12

were orthographically similar to the expected terminal words this finding suggests that the phonological codes that were associated with the homophone foils in the FOIL condition were responsible for the reduced amplitude of the N400 response. However, the magnitude of this influence was reduced, as in Experiment 3, which was demonstrated by the significantly larger N400 amplitudes that were elicited by the FOIL than by the CONGRUENT condition (see Appendix I, TableI2 for means). See Figure 12 for grand averages.

The influence of phonological codes associated with non-word stimuli was investigated in the fourth planned comparison. This planned comparison examined the amplitude differences between the non-word conditions which shared their phonological representations with either a homophone pair or a non-homophonic word. The amplitudes elicited by the PSEUDOFOIL-HOMOPHONE and PSEUDOFOIL-NONHOMOPHONE conditions were compared and were not found to differ significantly from each other. This analysis showed that the phonological codes that were associated with non-word stimuli elicited similar responses regardless of whether they were identical to homophone pairs or non-homophonic words (see Appendix I, TableI2 for means). See Figure 13 for grand averages.

The final comparison investigated the sensitivity of the N400 response to phonological codes that were associated with both word and non-word stimuli. This analysis compared the amplitudes elicited by the FOIL and PSEUDOFOIL-HOMOPHONE conditions. The results of the analysis revealed that there was not a significant difference in amplitude between these conditions. This analysis indicated that the phonological codes associated with words and non-words elicited similar N400 responses. The distribution of the N400 response was found to vary across the electrode sites (see Appendix I, TableI2 for means). See Figure 13 for grand averages.

Topographical Distribution

The repeated measures ANOVA which included Condition and Site as factors revealed that the size of the amplitudes that were associated with the N400 component varied

Figure Caption

Figure 13. Grand average waveforms at 15 sites for the CONGRUENT (solid green line), FOIL (dotted red line), PSEUDOFOIL-HOMOPHONE (dot dot dashed aquablue line) and PSEUDOFOIL-NONHOMOPHONE (long dashed blue line) stimulus conditions.

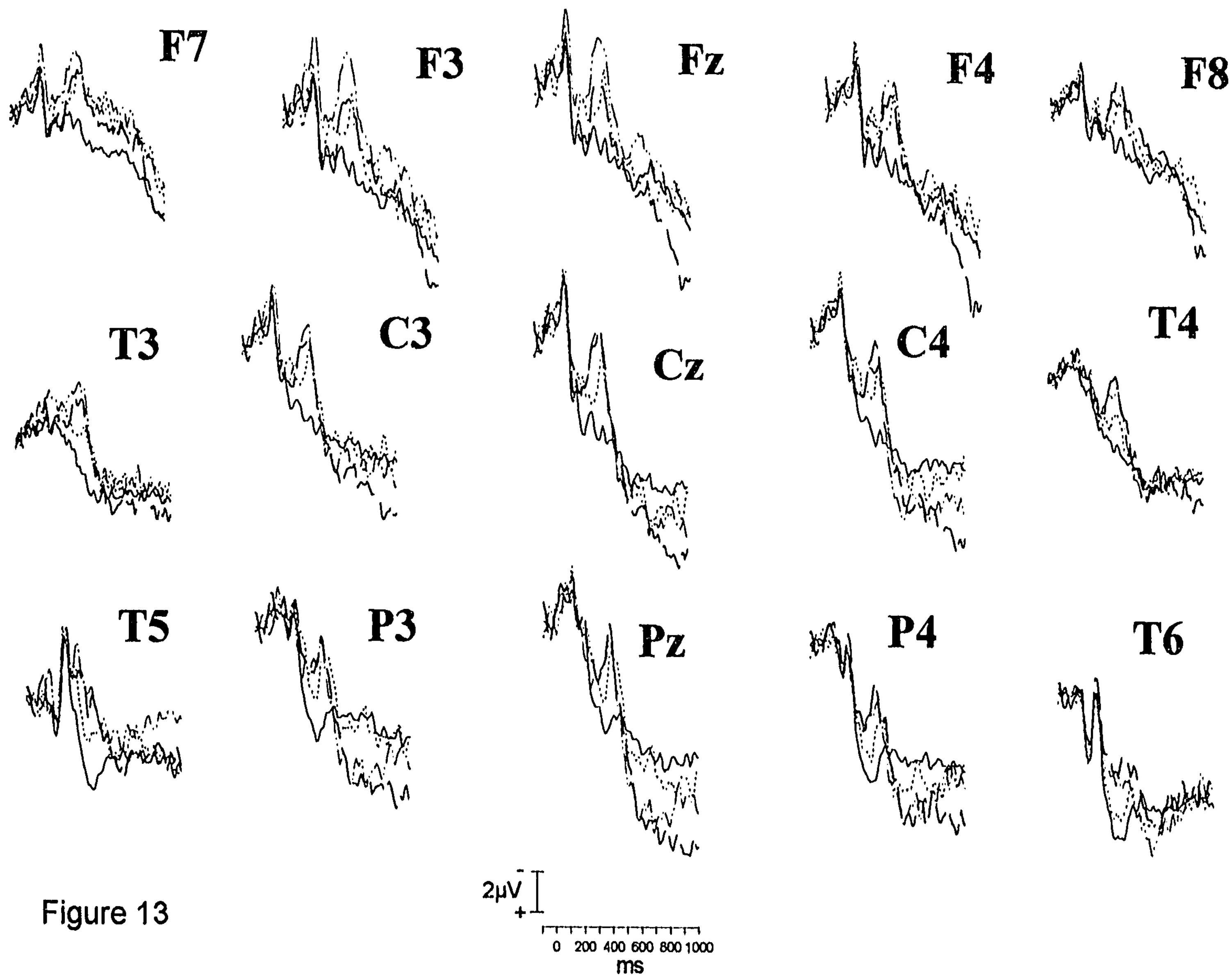
F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
2μV
-
+
0 200 400 600 800 1000
ms

Figure 13

consistently across the electrode sites. A post hoc analysis of this main effect revealed that the amplitudes that were associated with the right posterior temporal site (T6) were significantly smaller than all other sites. An exception to this was that T6 did not differ in amplitude from the right parietal site (P4). The amplitudes associated with the right parietal site (P4) were significantly smaller than those observed over the left anterior frontal (F3) and temporal (T3) sites and the left posterior frontal site (F7) (see Appendix I Table I3 for means). No other differences in amplitude were observed between the electrode sites. See Figures 12 and 13 for grand averages. A significant interaction was observed between the Condition and Site factors. However, this interaction did not remain significant following the normalization procedure.

The second analysis included Condition (6 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix I Table I4). There was a significant main effect for Condition which was reported in the first analysis. The results of this second analysis revealed that the amplitude of the N400 response varied reliably across the brain regions. A post hoc analysis of this main effect revealed that the frontal region elicited significantly larger amplitudes than did the parietal and temporal regions. The central region did not differ significantly in amplitude from any of the other brain regions (see Appendix I Table I5). The amplitudes that were associated with the N400 component were also found to vary across the brain hemispheres. This main effect for Hemisphere was due to the amplitudes observed over the left hemisphere being significantly larger than those observed over the right hemisphere (see Appendix I Table I5).

A significant interaction between the Region and Hemisphere factors was observed. A post hoc analysis of this interaction revealed that there was a tendency for the amplitudes observed over the left brain regions to be larger than those observed over the right brain regions. That is, the amplitudes observed over the left frontal, temporal and central regions were significantly larger than those observed over the right central, parietal and temporal regions.

Furthermore, the left parietal region was associated with larger N400 amplitudes than were the right parietal and temporal regions. This post hoc analysis also showed that the amplitudes that were associated with the brain regions varied reliably within each hemisphere. Within the left hemisphere the frontal region was associated with significantly larger amplitudes than the parietal region. In the right hemisphere the frontal region was associated with significantly larger amplitudes than the central, parietal and temporal regions and the central region was associated with significantly larger amplitudes than the temporal region. See Figure 14 for interaction.

A significant interaction involving the Condition, Region and Hemisphere factors was observed and remained significant following the normalization procedure. See Table 6 for interaction. The results of this analysis revealed that the amplitudes associated with the left hemisphere were typically larger than those that were associated with the right hemisphere. The amplitudes observed over the left parietal and temporal areas were significantly larger than those observed over the right parietal and temporal areas for all stimulus conditions. Larger left than right hemisphere amplitudes were observed over the central brain areas in the OS-HOMOPHONE, PSEUDOFOIL-HOMOPHONE and CONGRUENT conditions. The same pattern of results was observed over the frontal brain regions in the PSEUDOFOIL-HOMOPHONE and FOIL conditions. In contrast, the amplitudes that were observed over the central regions did not differ from each other in the OS-NONHOMOPHONE, PSEUDOFOIL-NONHOMOPHONE and FOIL conditions. Similarly, the amplitudes that were associated with the left and right frontal regions did not differ from each other in the OS-NONHOMOPHONE, OS-HOMOPHONE, PSEUDOFOIL-NONHOMOPHONE and CONGRUENT conditions.

The post hoc analysis also revealed that the amplitudes that were associated with the brain regions varied significantly across the stimulus conditions. In the OS-NONHOMOPHONE condition, the amplitudes that were observed over the left parietal brain region were significantly larger than those that were observed over all other brain regions. An

Figure Caption

Figure 14. Graph depicting a significant interaction between Region and Hemisphere factors for N400 amplitude data in Experiment 4.

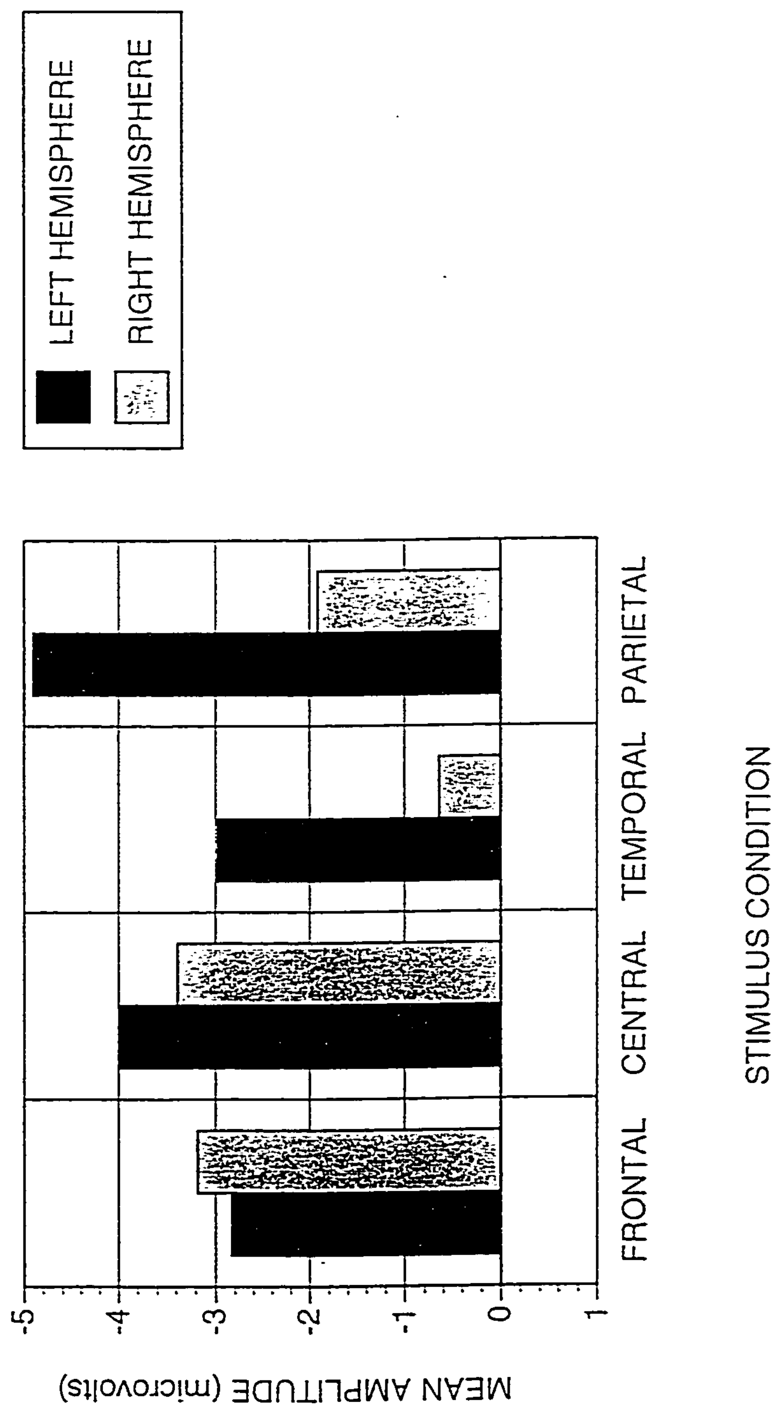
LEFT HEMISPHERE
RIGHT HEMISPHERE
MEAN AMPLITUDE (microvolts)
-5
-4
-3
-2
-1
0
1
FRONTAL
CENTRAL
TEMPORAL
PARIETAL
STIMULUS CONDITION

Figure 14

Table 6

Mean Amplitudes (in μV) (and Standard Deviations) for the Condition X Region X Hemisphere analysis for the N270 component in Experiment 1

	Left Hemisphere			
	Frontal	Central	Temporal	Parietal
Congruent	1.01 (3.93)	2.91 (3.79)	1.85 (2.93)	2.97 (3.71)
Foil	-2.73 (5.36)	-1.34 (4.40)	-1.05 (4.73)	-2.11 (5.22)
Pseudofoil-Homophone	-4.40 (5.48)	-2.48 (3.37)	-1.90 (5.20)	-0.25 (4.58)
OS-Homophone	-2.54 (6.22)	-1.88 (3.77)	-1.48 (5.34)	-1.01 (5.98)
Pseudofoil-Nonhomophone	-3.35 (4.08)	-1.89 (2.08)	-2.83 (3.30)	-2.64 (3.47)
OS-Nonhomophone	-2.83 (6.20)	-2.97 (4.37)	-4.00 (5.63)	-4.90 (5.92)

	Right Hemisphere			
	Frontal	Central	Temporal	Parietal
Congruent	1.92 (4.07)	4.58 (4.08)	3.92 (3.03)	4.38 (3.70)
Foil	-1.54 (4.94)	2.11 (4.55)	-0.14 (5.75)	1.53 (6.98)
Pseudofoil-Homophone	-2.22 (5.00)	1.04 (3.14)	0.34 (4.64)	1.60 (4.12)
OS-Homophone	-2.02 (4.90)	0.72 (2.77)	-0.64 (5.05)	0.58 (4.58)
Pseudofoil-Nonhomophone	-2.70 (3.50)	0.62 (3.17)	-1.50 (3.52)	-0.25 (3.77)
OS-Nonhomophone	-3.18 (4.67)	-0.64 (3.05)	-3.38 (4.92)	-1.92 (1.16)

exception was that the left central region did not differ in amplitude from the left parietal region. However, the amplitudes observed over the left central region were significantly larger than those observed over the left frontal region and the right parietal and temporal regions. The right central and frontal regions, which did not differ from each other, were associated with significantly larger amplitudes than were the right parietal and temporal regions. Finally, the amplitudes that were observed over the right parietal and left temporal and frontal regions were significantly more negative than were the amplitudes associated with the right temporal region. Thus, the pattern of ERPs that was elicited by this stimulus condition was enhanced over the left parietal and central areas.

This pattern differed from the that observed in the OS-HOMOPHONE condition. The amplitudes that were associated with all of the regions in the left hemisphere and the right frontal and central regions were significantly larger than those that were associated with the right parietal and temporal regions. The right frontal region produced significantly larger amplitudes than did the right central region. The left frontal region was also associated with significantly larger amplitudes than were the right central and left temporal regions. The right frontal and central regions were also associated with amplitudes that were significantly more negative than those associated with the right parietal and temporal regions. The left frontal region was also associated with significantly larger amplitudes than the left temporal region. Finally, both frontal regions were associated with significantly larger amplitudes than did the other regions in the right hemisphere. Thus, the pattern of ERPs that was elicited by this stimulus condition tended to be more enhanced over the left and right frontal and left central areas.

Similar distributions were observed in the remaining stimulus conditions. The left and right frontal and left temporal brain regions were associated with significantly larger amplitudes than were the right central, parietal and temporal regions in the PSEUDOFOIL-NONHOMOPHONE condition. In addition, the amplitudes observed over the left and right central and left parietal regions were significantly more negative than were those observed over the right parietal and temporal areas. Similarly, the left frontal region was associated with significantly larger amplitudes than were the other brain regions in both hemispheres in the PSEUDOFOIL-HOMOPHONE condition. Amplitudes that were observed over the left temporal and central regions and the right frontal regions were significantly more negative than were those observed over the left and right parietal regions and the right central and temporal regions. The left parietal and right central regions produced significantly larger amplitudes than were observed over the right parietal areas. Finally, the left parietal region was associated with significantly larger amplitudes than the right temporal region. These patterns of ERPs indicate that the pseudofoil conditions had similar topographical distributions.

In addition, the results indicated that the FOIL condition was associated with larger frontal amplitudes. As in the pseudofoil conditions the left frontal region was associated with amplitudes that were significantly larger than those observed in all other regions. The left parietal and temporal and right frontal regions were associated with larger amplitudes than did the right central, parietal and temporal regions. Similarly, the left and right central regions were associated with amplitudes that were significantly more negative than were those observed over the right parietal and temporal areas. This pattern of ERPs was similar to that observed in the CONGRUENT condition.

The left frontal region was associated with significantly larger amplitudes than were the left and right central and parietal regions and the right temporal region. Also, the left temporal, central and parietal regions and the right temporal and frontal regions were associated with significantly larger amplitudes than the right parietal and central regions. The left temporal and right frontal regions were associated with significantly larger amplitudes than the right temporal region. These findings indicate that with the exception of the OS-NONHOMOPHONE condition, the N400 response was generally enhanced over the left frontal areas.

The results of the post hoc analysis also indicated that the amplitudes that were associated with the brain regions varied reliably across the stimulus conditions. The amplitudes that were associated with both central and parietal regions in the OS-NONHOMOPHONE condition were significantly larger than those observed over the same areas in the other stimulus conditions. In contrast, the amplitudes that were observed over the frontal and temporal areas in this stimulus condition were generally larger than those elicited by the FOIL, CONGRUENT and both pseudofoil conditions. However, these amplitudes did not tend to differ from those observed in the OS-HOMOPHONE condition.

Similarly, the amplitudes that were associated with both central and parietal regions in the OS-HOMOPHONE condition were generally significantly larger than all of the other stimulus conditions with the exception of the OS-NONHOMOPHONE condition. However, the amplitudes that were observed over both temporal and frontal regions were significantly larger than those elicited by only the CONGRUENT and FOIL conditions. This pattern of results was not observed in either of the pseudofoil conditions. The amplitudes that were associated with all brain regions in both of these conditions as well as the FOIL condition generally differed only from the CONGRUENT condition. An exception to this was that the amplitudes observed over the left frontal region in the PSEUDOFOIL-HOMOPHONE condition were significantly larger than those in all other stimulus conditions except for the OS-NONHOMOPHONE condition. See Figure 14.

A significant interaction involving the Condition and Region factors was observed in this analysis. However, this interaction did not remain significant following the normalization procedure indicating that the amplitudes associated with the brain regions did not vary consistently across the stimulus conditions. Finally, a significant interaction involving the Condition and Hemisphere factors was observed in the analysis but did not remain significant following the normalization procedure. See Figures 12 and 13 for grand averages.

Latency

The latency data from individual averaged waveforms was analyzed in two separate analyses. The first analysis included Condition (6 levels) and Site (15 levels) as factors in an ANOVA with repeated measures (see Appendix I Table I6). This analysis revealed that the latency of the N400 response varied reliably across the electrode sites. A post hoc analysis of this main effect revealed that the latencies that were associated with the left and right posterior temporal sites (T5 and T6, respectively) were significantly longer than those that were associated with the left central (C3), parietal (P3) and anterior temporal (T3) sites and the midline parietal site (Pz). Although the latency of the N400 response was found to vary consistently across electrode sites it did not vary reliably across the stimulus conditions. Furthermore, there was no significant interaction between the Condition and Site factors (see Appendix I Table I7 for means). See Figures 12 and 13 for grand averages.

The second analysis included Condition (6 levels), Region (4 levels) and Hemisphere (2 levels) as factors in an ANOVA with repeated measures (see Appendix I Table I8). This analysis revealed that the latencies associated with the N400 response varied consistently across the brain regions. A post hoc analysis of this main effect for Region showed that the frontal and temporal regions were associated with significantly longer latencies than was the central region. The latencies that were associated with the parietal region did not differ significantly from any of the other brain regions (see Appendix I Table I9 for means). No other significant main effects or interactions were observed in this analysis. See Figures 12 and 13 for grand averages.

Discussion

Previous behavioural research has shown that the inclusion of pseudohomophones in the stimulus set can influence the extent to which phonological codes are used during the word identification process (Davelaar et al., 1978; M^{c}Quade, 1981). The intent of the present experiment was to use ERPs to investigate whether phonological recoding would occur during silent reading when pseudohomophones were included in the stimulus set. It was predicted that the phonological codes that were associated with both lexical and non-lexical stimuli would mediate the word identification process.

The results of this study suggested that phonological recoding occurred during this sentence reading task. A N400 response was elicited by phonologically unexpected terminal words that were incongruous to the sentence context (i.e., OS-HOMOPHONE and OS-NONHOMOPHONE conditions). As seen previously, the amplitude of this N400 response was significantly larger than the amplitude that was associated with the FOIL condition where the stimulus was incongruous but the phonology was correct. Insofar as these stimuli were semantically unexpected and were equated in terms of their orthographic similarity to the high cloze probability words it appears that the N400 component responded differentially depending upon whether or not the terminal words were phonologically expected.

Further support for phonological recoding was obtained from the stimulus conditions in which pseudofoils were manipulated. The present results showed that the N400 amplitudes elicited by phonologically expected non-lexical stimuli in the pseudofoil conditions (PSEUDOFOIL-HOMOPHONE and PSEUDOFOIL-NONHOMOPHONE conditions) did not differ from the N400 responses associated with the FOIL condition. In addition, these phonologically expected but incongruous stimuli produced significantly smaller N400 responses than did incongruous sentence-ending words that were phonologically unexpected in the OS-HOMOPHONE and OS-NONHOMOPHONE conditions. These findings differ from Experiment 3 inasmuch as non-lexical stimuli produced N400 responses that did not differ in amplitude from those produced by the incongruous sentence-ending words. The difference between these experiments appears to be attributable to the non-lexical stimuli being phonologically expected in the present experiment whereas, the non-lexical stimuli in the previous experiment were phonologically unexpected.

The difference between these experiments has two important implications. First, this finding suggests that the N400 response is not sensitive to the lexical status of the sentence-ending stimuli. This observation is in keeping with the results of Experiment 3 which also found the N400 amplitude did not vary according to lexicality of the stimuli. Second, these results suggest that the phonological recoding effect is not limited to the homophone pairs. That is, whether the non-word stimuli shared their phonological codes with homophone pairs or with non-homophonic words similar N400 amplitudes were produced.

The observation that the phonological codes that were associated with word and non-word stimuli influenced task performance suggests that these codes are activated during the word identification processes. The non-word stimuli are obviously not represented in the mental lexicon. In Experiment 3 phonologically unexpected non-words produced N400 responses that were comparable to those produced by phonologically unexpected incongruous words. However, the N400 responded differentially to the orthographically similar non-word stimuli in Experiment 3 and the pseudofoils in the present experiment which also satisfied the criteria for orthographic similarity. In the case of the present experiment it seems likely that the reduced N400 amplitude was due to the activation of phonological codes during the sentence reading task.

These results suggest that phonological recoding occurred however, there is also evidence indicating that phonological factors that seemed to be important in Forbes (1993) and Experiment 2 were diminished. The N400 amplitudes that were associated with the FOIL and both pseudofoil conditions were significantly smaller than those that were elicited by incongruous words that were phonologically unexpected. However, the amplitudes that were associated with phonologically expected stimuli (FOIL, PSEUDOFOIL-HOMOPHONE and PSEUDOFOIL-NONHOMOPHONE conditions) were significantly larger than those elicited by the congruous terminal words. This finding indicated that the phonological codes associated with these lexical and non-lexical stimuli did not overshadow the effect of violating the semantic expectancy that was generated through semantic priming.

The observation that phonologically expected but semantically incongruous stimuli produced different ERP patterns than the CONGRUENT condition was different from the results observed in Experiment 2 and by Forbes (1993). However, this finding is consistent with the pattern of ERP findings observed in Experiments 1 and 3. As indicated previously, Experiments 1 and 3 included manipulations that have been demonstrated in behavioural research to reduce the influence of phonological codes (Stone & Van Orden, 1993; Marmurek & Kwantes, 1996). The present experiment produced a similar pattern of ERPs inasmuch as the phonologically expected but incongruous stimuli produced significantly larger N400 amplitudes than the CONGRUENT condition. This finding indicates that the phonological codes associated with the homophone foils and pseudofoils in the present experiment did not overshadow the effect of violating the semantic expectancy for the terminal words for the sentences. Thus, it seems reasonable to assume that the inclusion of non-word stimuli that shared their phonological representations with real English words discouraged, but did not terminate, the use of phonological codes during reading.

Chapter Seven

General Discussion

The following discussion will take the form of a brief recapitulation of the major findings of these experiments that address the central issues of the thesis. The intent of this series of experiments was to investigate 1) whether phonological recoding occurred during silent reading of sentences containing phonologically ambiguous stimuli (i.e., homophones, pseudohomophones); 2) whether factors that have been observed to reduce the magnitude or abolish the effects of the phonological recoding in behavioural studies produce similar findings in ERP research; and, 3) the sensitivity of the N400 response to semantic priming during a sentence reading task. The results of these studies have important implications for two issues in the study of visual word recognition. First, they demonstrate that phonological recoding occurs during the silent reading of sentences and second, they provide ERP evidence indicating that the importance of phonological factors during word identification can be diminished by requiring subjects to perform a semantic judgement task during the experiment or by the inclusion of non-word stimuli. Finally, the findings have relevance to two issues in ERP research: They support the position that the N400 component is separate and distinct from earlier occurring negative components in the ERP waveform and they confirm previous research that the N400 is sensitive to semantic priming.

Phonological Influences during Silent Reading

The present research investigated whether phonological codes influenced the processes involved in word identification. Subjects read a series of unrelated sentences with high contextual constraint in all four experiments reported in this dissertation. All of the sentences had a high level of contextual constraint which made the terminal words very predictable. The phonological, orthographic and semantic representations of the sentence-ending words were manipulated in these experiments. ERPs were used to investigate the effects of these manipulations as they occurred in real time (Zwitserlood, 1989). The major goal of the dissertation was to investigate whether phonological codes are used during silent reading and whether the importance of these codes during reading can be diminished by using some of the factors that have been shown in behavioural research to discourage the use of phonologically based processing strategies.

A study conducted by Forbes (1993) reported evidence supporting phonological recoding during the silent reading of sentences. As mentioned previously, a N400 response was elicited by incongruous terminal words that were phonologically unexpected and that were not primed by the preceding sentence context (INCONGRUENT condition). This N400 response was significantly larger in amplitude than the N400 associated with incongruous homophone foils that were phonologically expected and that did not differ from the terminal words in the CONGRUENT condition. Inasmuch as the terminal words in the INCONGRUENT and FOIL conditions were semantically incongruous to the sentence context, the difference in N400 amplitudes was attributed to the use of phonological codes in the case of the FOIL condition which accessed the lexical representation for the semantically appropriate homophone.

Experiment 1 of the present series of experiments was conducted to investigate whether the influence of phonology observed by Forbes (1993) would be diminished by the inclusion of a semantic judgement task. Previous research has indicated that task requirements and task instructions can influence whether phonological codes are used during a behavioural task (Hawkins et al., 1976; Coltheart et al., 1991; 1994). The results of Experiment 1 indicated that the FOIL condition produced a N400 response that did not differ significantly in amplitude from the N400 produced by the INCONGRUENT condition. This result indicates that the N400 component did not respond differentially to the incongruous sentence-ending stimuli (but phonologically appropriate) in these circumstances.

This finding is in contrast to the results reported by Forbes (1993) who observed that the N400 amplitudes produced by the FOIL condition were significantly smaller than those produced by the INCONGRUENT condition. The absence of a significant difference between these stimulus conditions in Experiment 1 suggests that the phonological codes associated with the homophone foils in the FOIL condition did not overshadow the effect of violating the semantic expectancy as was the case in Forbes (1993). This finding indicates that the use of the semantic judgement task in Experiment 1 discouraged subjects from relying on phonological codes during the reading of sentences.

Further support for this position was obtained from the comparison of N400 amplitudes associated with the FOIL and CONGRUENT conditions. The results of Experiment 1 showed that the FOIL condition produced significantly larger N400 amplitudes than did the CONGRUENT condition. The observation that the N400 responded differentially to these stimulus conditions indicates that the phonological codes associated with the semantically incongruous homophone foils in the FOIL condition did not influence the elicitation of the N400 response in a similar manner to that observed by Forbes (1993) who did not observe a significant difference in amplitude between these stimulus conditions. Given that the only difference between the two experiments was the semantic judgement task it seems reasonable to conclude that the difference in the ERP patterns observed by Forbes (1993) and in Experiment 1 is due to the inclusion of the semantic judgement task which forced subjects to attend to the orthographic representations of the sentence-ending words.

While the inclusion of the semantic judgement task appeared to reduce the importance of phonological codes during the word identification process, the behavioural data suggest that these codes also subjects' ability to make decisions regarding the semantic appropriateness of the sentence-ending words. Subjects were significantly more accurate in deciding that the terminal words in the INCONGRUENT condition were semantically inappropriate, than deciding whether terminal words in the FOIL condition were semantically incongruous. This finding indicates that the phonological codes associated with the homophone foils influenced word identification and made the decision process more difficult. This effect was not attributable to a speed-accuracy trade-off since the responses made to stimuli in both of these conditions did not differ significantly in latency from each other.

Thus, the ERP results of Experiment 1 indicate that phonological codes did not influence the on-line processes involved in word identification when subjects were required to perform a semantic judgment task. However, the later processes that were involved in decision making suggests that phonological codes made the decisions more difficult. Overall, the findings from Experiment 1 indicate that manipulating task requirements and instructions can influence whether phonological codes are used during the processes involved in word identification. These findings support previous behavioural research which has also provided evidence to suggest that changes in task instructions can discourage the use of phonological codes during isolated word paradigms (Coltheart et al., 1991; 1994).

An issue that has been investigated in behavioural research is the extent to which the evidence supporting phonological recoding can be attributed to orthographic similarity between anticipated stimuli and the stimuli that are actually presented (Van Orden, 1987; Jared & Seidenberg, 1991; Coltheart et al., 1994; Daneman & Stainton, 1991). Experiment 2 investigated whether the evidence reported by Forbes (1993) in support of phonological recoding could actually be attributed to the orthographic similarity between the expected terminal words that were primed by the sentence context and the incongruous terminal words that were used to complete the sentences. The degree to which the incongruous sentence-ending words were orthographically similar to the semantically appropriate terminal words was manipulated.

The results of this study showed that the orthographically similar (OS) and dissimilar (OD) terminal words elicited N400 responses that did not differ from each other in amplitude. That is, the N400 component did not respond differentially to incongruous stimuli on the basis of whether they were orthographically similar or dissimilar to the highly probable terminal words. However, the results also indicated that the N400 did respond differentially to semantically incongruous terminal words depending upon whether they were phonologically expected. The phonologically expected homophone foils were associated with amplitudes that were significantly reduced in comparison to the amplitudes elicited by phonologically unexpected stimuli in the OS and OD conditions. This finding suggests that the phonological codes influenced the word identification process during reading such that a N400 response was not elicited by these semantically incongruous stimuli.

Further, the N400 amplitudes associated with the FOIL condition did not differ significantly from those elicited by the CONGRUENT condition. Inasmuch as the homophone foils were semantically incongruous to the sentence context the similar N400 amplitudes observed in these stimulus conditions suggests that the phonological codes associated with these stimuli influenced the processes involved in word identification. This result can not be attributed to the orthographic similarity of the homophone foils to their homophone partners since these terminal words produced smaller N400 responses than those in the OS condition which also satisfied the criteria for orthographic similarity. Thus, these findings provide support for and extend previous behavioural research supporting phonological recoding and indicates that this effect is not due to the orthographic similarity between the expected and presented terminal words (Van Orden, 1987; Jared & Seidenberg, 1991; Daneman & Stainton, 1991).

The pattern of ERPs observed in Experiment 2 replicated the findings reported by Forbes (1993) who observed that the FOIL condition produced N400 amplitudes that were significantly smaller than those elicited by the phonologically unexpected terminal words in the INCONGRUENT condition. However, the findings from Experiment 2, like those reported by Forbes (1993), were in contrast to the results of Experiment 1. Inasmuch as the subjects were required to simply read the sentences in Experiment 2 and in Forbes (1993), they were not forced to attend to the orthographic representations of the sentence-ending words as in Experiment 1 when they performed the semantic judgement task. This difference between the experiments suggests that while phonological codes are used during the reading of sentences the importance of these codes may be reduced when subjects are driven to rely on orthographic codes in order to optimize task performance.

Another factor that might force subjects to attend to the orthographic representations of terminal words is the inclusion of non-word stimuli in the stimulus set. This issue was investigated in Experiment 3 using ERPs by including pronounceable non-words in the stimulus set. These non-words did not share their phonological representations with any real English words. The results showed that the N400 response that was elicited by the non-words in Experiment 3 did not differ from the N400 response elicited by the incongruous terminal words that were phonologically unexpected. These results support previous ERP research which has demonstrated that non-word stimuli produce N400 responses which do not differ from semantically incongruous, and therefore unprimed, words (Rugg & Nagy, 1987).

As in the previous study the amplitude of the N400 response was not influenced by whether the incongruous stimuli were orthographically similar or dissimilar to the expected terminal words of the sentences. However, the N400 responded differentially to incongruous stimuli based on whether they were phonologically expected. The N400 responses elicited by phonologically unexpected words and non-words were significantly larger in amplitude than the N400 elicited by the phonologically expected but semantically incongruous homophone foils from the FOIL condition. The results of Experiment 3 also showed that the FOIL condition produced N400 amplitudes that were significantly larger than those produced by the CONGRUENT condition. This finding, which was also observed in Experiment 1, suggests that the importance of phonological factors was reduced in Experiment 3 and resulted in larger N400 amplitudes in the FOIL than in the CONGRUENT condition.

This pattern of ERPs is proposed to be attributable to the inclusion of non-words in the stimulus set. Although subjects were required to simply read the sentences as in Experiment 2 and Forbes (1993) the use of non-word stimuli presumably caused subjects to focus on the orthographic representations of the terminal stimuli and resulted in a pattern of ERPs that was similar to Experiment 1. These results support previous behavioural research which has shown that the importance of phonological codes is reduced by including non-words in the stimulus set (McNamara & Healy, 1988).

Finally, Experiment 4 investigated whether phonological recoding would occur if the non-word stimuli presented in the stimulus set shared their phonological representations with either homophone pairs or non-homophonic words. The results of this study showed that non-word stimuli that were phonologically expected (PSEUDOFOIL-HOMOPHONE, PSEUDOFOIL-NONHOMOPHONE) produced significantly smaller N400 responses than those elicited by semantically incongruous terminal words that were phonologically unexpected (OS-HOMOPHONE, OS-NONHOMOPHONE). This result is in contrast to Experiment 3 which showed that non-word stimuli elicited N400 responses which did not differ from those elicited by incongruous terminal words that were phonologically unexpected. However, the non-word stimuli in Experiment 3 did not share their phonological representations with the semantically expected terminal words for the sentences. Presumably, the reduced N400 amplitudes that were observed to the non-word stimuli in Experiment 4 were due to the influence of the phonological codes that were associated with the pseudohomophones.

This position is supported by the observation that the phonologically expected non-word stimuli produced N400 responses that did not differ from the N400 responses produced by the homophone foils in the FOIL condition which were also smaller than the responses associated with the phonologically unexpected incongruous stimuli. These results indicate that the N400 responded differentially to the incongruous stimuli depending upon whether they were phonologically expected but was not influenced by the lexical status of the incongruous stimuli. These results suggest that the phonological codes influenced the word identification process and overshadowed the effect of violating the semantic expectancy generated through semantic priming.

Overall, these results confirm previous research that the N400 is sensitive to semantic priming (Kutas & Van Petten, 1988). This response was activated when unprimed stimuli were used to complete sentences with high contextual constraint. However, there was an exception to this pattern of ERPs inasmuch as the phonological codes associated with the sentence-ending stimuli were observed to influence the elicitation of the N400 response. These results provide strong evidence in support of phonological recoding during the silent reading of sentences. In addition, these studies have shown that the importance of phonological codes can be affected by the same factors that have been shown to influence the use of phonological codes during behavioural tasks.

A recent study reported by Niznikiewicz and Squires (1996) also investigated the influence of phonological representations during visual word recognition. This study examined whether the phonological codes influenced the word identification processes during a sentence reading task and a word-pair paradigm and if the nature of these influences differed between tasks. In their study, each subject completed the sentence reading task and the word-pair task.

ERPs were recorded to the terminal words of the sentences and to the second words that were presented in each word-pair. The results of the study showed that a N400 response was elicited by incongruous stimuli that were phonologically expected homophone foils or phonologically unexpected terminal words of the sentences. However, these results are difficult to interpret within the present context due to the manner in which the data were scored. The N400 response was scored as the most negative peak that occurred in the latency period of 300 ms to 700 ms and had a mean latency of 593 ms (range = 73 ms).

The latency period reported by Niznikiewicz and Squires is in contrast to the latency periods reported in all other ERP studies. The N400 response is typically associated with a negative-going component which commences about 200 ms post-stimulus, peaks about 400 ms post-stimulus and terminates at approximately 600 ms post-stimulus (Mitchell et al., 1993; Besson et al., 1992; Kutas & Hillyard, 1980a, b and c). Inasmuch as the N400 component, unlike other neural components (e.g., P300), has been shown to be relatively resistant to latency shifts (Connolly & Phillips, 1994) it is unlikely that the component reported by Niznikiewicz and Squires actually reflects the same semantic priming process that is typically associated with the N400 response. Consequently, the results of their study can not be interpreted within the context of the present series of experiments.

The Uniqueness of the N400 Component

The results of this series of studies support the position that the N400 response is a unique neural component or a late manifestation of earlier occurring negative components (e.g., N200, N270, PMN) (Polich, 1985; McCallum, Farmer & Pocock, 1984; Pritchard et al., 1991; Connolly & Phillips, 1994; Connolly et al., 1995). As pointed out previously, neural components that are reliably produced by different cognitive manipulations are presumed to reflect separate cognitive processes (Kramer & Donchin, 1987). Research that has directly investigated this issue suggests that the N400 and the negative components that have been observed in earlier latency periods are elicited by different stimulus factors (Connolly et al., 1990; 1992; 1995). The results of the present series of experiments lend support to the position that the N400 response is a unique neural component.

The N400 component, which has been shown to occur reliably to violations in semantic expectancy (Kutas & Van Petten, 1988; Connolly et al., 1995), was used to examine the influence of phonology during the sentence reading task. The amplitude of the N400 component did not vary according to whether the incongruous stimuli were 1) words or nonwords or 2) orthographically similar or dissimilar to the expected terminal words. However, the N400 did respond differentially to incongruous stimuli depending on whether they were phonologically expected. In all experiments the phonologically unexpected stimuli produced larger N400 amplitudes than did the phonologically expected stimuli. These findings indicate that while the N400 component was sensitive to the phonological codes associated with the sentence-ending stimuli.

In contrast to the N400 response the earlier occurring N270 component was not elicited reliably by the stimulus conditions. The post hoc analysis reported by Forbes (1993) suggested that the N270 component was sensitive to the level of orthographic similarity shared between the homophone foils in the FOIL condition and their homophone partner. Homophone foils that violated the criteria for orthographic similarity elicited significantly larger N270 responses than did the homophone foils that satisfied these criteria. The results of Experiment 2 showed a similar pattern of findings inasmuch as the semantically incongruous terminal words that were orthographically dissimilar (OD condition) to the expected terminal words produced significantly larger N270 responses than did the incongruous stimuli that were orthographically similar (OS condition) to these sentence-ending words.

Although the findings from Forbes (1993) and Experiment 2 suggest that the N270 response was tied to deviations in orthographic expectancy for the sentence-ending stimuli the results from other experiments in this series are less convincing. A semantic judgement task was used in Experiment 1 in an effort to force subjects to attend to the orthographic representations of the sentence-ending words. The subjects had a high level of response accuracy on the semantic task suggesting that they had in fact used orthographic codes during reading. Despite their reliance on orthographic codes the results of the post hoc analysis, unlike Forbes (1993), did not indicate that the N270 responded differentially to homophone foils that were orthographically similar and dissimilar to their homophone partner.

Similarly, the results from Experiment 3 showed that the amplitude of the N270 response did not vary according to the level of orthographic similarity of the incongruous stimuli as it was observed to do in Experiment 2. These findings indicate that the N270 component, unlike the N400 component, was not elicited reliably across the present series of experiments. Further, the N270 response was not elicited by deviations in semantic expectancies that were generated through semantic priming. This observation suggests that the processes underlying the N400 and N270 components are separate.

Topographical Distribution of the N400 Component

Evidence supporting the position that the N400 is a unique neural component was also obtained from the scalp topography associated with this response. Previous research has shown that the N400 response can be enhanced over different brain areas. Although the N400 is typically enhanced over the centro-parietal brain regions (Kutas & Van Petten, 1988) other topographical distributions have been reported. The results of Experiment 2 and Forbes (1993) showed that the N400 responses were centro-parietally distributed whereas, the N400 responses that were observed Experiments 1 and 3 were enhanced over parietal areas and were distributed evenly across the electrode sites, respectively. Finally, the N400 response was enhanced over the frontal brain regions in Experiment 4.

The topographical distributions of the N400 response that were observed within the present series of studies are consistent with the distributions reported by other researchers (Pritchard et al., 1991). The explanation for these differences in topography is not clear however, the N400 response is elicited reliably by deviations in semantic priming. Therefore, it seems reasonable to propose that the variation in topographical distributions may be tied to differences in task requirements or instructions (Connolly et al., 1995).

The N400 responses observed in this series of experiments support the position that differences in task requirements can result in altering the topographical distribution of this component. As mentioned earlier, the N400 response is typically enhanced over centro-parietal brain regions during sentence reading tasks that require subjects to read the sentences for comprehension (e.g., Connolly et al., 1995; Kutas & Hillyard, 1980a, b and c). This distribution was observed in Experiment 2 and by Forbes (1993) in which subjects simply read the sentences for comprehension. These experiments did not manipulate any factors that have been shown to reduce the importance of phonological codes in behavioural tasks.

In contrast, the results from Experiment 1 showed that the N400 response was associated with a different topographical distribution. Experiment 1 required subjects to perform a semantic judgement task in order to force them to attend to the orthographic representations of the terminal words for the sentences. Similarly, Experiments 3 and 4 included non-words and pseudohomophones, respectively, in the stimulus sets since previous behavioural research has shown that these manipulations can alter the use of phonological codes during word identification (McNamara & Healy, 1988; Coltheart et al., 1991; 1994). The ERP patterns from these experiments indicated that these experimental manipulations diminished the importance of phonological codes during silent reading. Thus, it is reasonable to presume that the changes in task requirements was responsible for the differences in topographical distributions associated with the N400 responses in each of these experiments.

In contrast to the N400 response, the topographical distribution of the earlier occurring N270 component was enhanced over temporal and centro-temporal brain regions. Similar topographical distributions have been observed for negative components that precede the N400 response. The N270 component has been observed to be enhanced over fronto-temporal brain areas (Connolly et al., 1995) and the PMN has been shown to be fronto-centrally distributed or equally distributed across the electrode sites (Connolly & Phillips, 1994). The topographical distributions that are associated with the earlier occurring negativities are not consistent with the distributions that are associated with the N400 response. The differences in the topographical distributions that are associated with these components suggests that different populations of cells are associated with these neural responses.

Further support for this has been obtained from research aimed at localizing the generators for these neural components using magnetoencephalography (MEG) recordings (Arthur, Schmidt, Kutas, George & Flynn, 1990). As with EEG recordings MEG recordings are able to provide excellent temporal resolution of brain processes. However, MEG also provides good spatial resolution for these processes. Consequently, MEG recordings can be used to localize the generators that are associated with specific brain components.

Recent research indicates that certain neural components can be localized to specific brain regions. The evidence obtained from the MEG studies suggest that the neural generators for the N400 and earlier occurring negativities such as the N200 are different. If different neuronal cells are involved in the generation of the components then it can be concluded that the processes underlying them are separate and distinct.

A good example of this research is a study conducted by Helenius, Salmelin, Service and Connolly (1998). These investigators studied the brain areas that were engaged in processing the meaning of visually presented sentences. In this study, subjects read a series of unrelated sentences and MEG recordings were obtained for the terminal words of the sentences. The terminal words in sentences were either congruous or incongruous to the sentence context. The congruous sentences were completed using either the high cloze probability word or with a low cloze probability word that was semantically congruous but unexpected. The semantically inappropriate words either shared their first 2-4 letters with the expected terminal words or they did not.

MEG recordings were found to vary across the stimulus conditions. The level of activation for the high cloze probability words did not differ from the noise levels. Both types of incongruous endings were associated with significantly higher levels of activation than were the congruous but rare terminal words. These recordings were pronounced in the superior temporal gyrus of left hemisphere and started at 300 ms and lasted until 600 ms and 500 ms post-stimulus for the incongruous and rare endings, respectively. These findings demonstrate that increasing levels of activation are related to decreasing levels of semantic expectancy. The higher levels of activation are associated with the N400 response since this component has been shown to be elicited reliably by the incongruous terminal words. Thus, these findings suggest that the N400 response originates in the left superior temporal gyrus.

Further evidence that the N400 response originates in the left superior temporal gyrus was obtained from a study that was conducted in the auditory modality (Connolly, Alho, Cheour-Luhtanen, Lehtokoski, Ilmoniemi, Huotilainen & Virtanen, 1998). In this study subjects listened to a series of sentences and MEG recordings were obtained for the terminal words of the sentences. The terminal words of the sentences were either semantically congruous or incongruous to the sentence context. As in the visual modality the results indicated that the N400 was generated in the left superior temporal gyrus.

Evidence has been obtained which suggests that the N2-type responses can also be localized using MEG recordings. These recordings indicate that the N2-type responses (e.g., Mismatch Negativity, Processing Negativity, PMN) can also be localized to the temporal brain regions. However, the generators for these responses are located in different areas of the temporal lobe than generators of the N400 component. An exception to this is the N2b component, a member of the N2 family, which presently can not be localized using MEG recordings.

In the face of variable topographical distributions this evidence seems to be the most compelling in suggesting that the N400 is a unique neural component (Kramer & Donchin, 1987). These findings demonstrate that brain recordings can be used to isolate the processes involved language. While the evidence from the present research indicates that the N400 reflects processes related to semantic integration the findings also indicate that the N270 component was sensitive to a different type of process involved in language.

Implications for Models of Word Recognition

The present research supports the position that phonological codes influence the processes involved in word identification. As mentioned previously, the basic assumption that is shared by all versions of the dual-route model is that word identification can proceed through more than one processing route (Coltheart et al., 1993). According to the model, word identification for familiar words occurs via the lexical route when the orthographic representations associated with the words directly activate the lexical representations that are stored within the mental lexicon. In contrast, the model proposes that unfamiliar words and non-words are identified through the non-lexical route when orthographic representations activate the corresponding phonological representations which in turn activate the stored lexical representations associated with these stimuli. Thus, this model proposes that phonological codes can be used when stimuli are identified through the non-lexical route but not when stimuli are identified through the lexical route.

Despite the allowance that is provided by the dual-route model for phonological influences during word identification some researchers have argued that these codes are unlikely to be used during this process (Humphreys & Evett, 1985) but rather are used after word identification occurs (Levy, 1977). This position is based upon the rationale that the processing time associated with the non-lexical route would be longer than that associated with the lexical route. It is argued that the activation of phonological codes in the non-lexical route represents an extra step in the word identification process that is not required in the lexical route (Humphreys & Evett, 1985). Insofar as both routes operate in parallel the word identification process would be completed sooner by the lexical route because it does not require that phonological codes be activated during word identification. Thus, phonological codes are unlikely to assume an active role in the identification of familiar words since the lexical route would have identified these words prior to the completion of the processes associated with the non-lexical route.

Much of the research that has provided support for the dual-route model has relied on behavioural paradigms such as naming tasks and lexical decision tasks. This research has typically relied upon differences in response accuracy and latency between stimulus conditions to determine whether phonological codes influenced task performance. Performance associated with homophone foils or pseudohomophones that differs significantly from the other stimulus conditions is taken as evidence for phonological recoding. As indicated previously, evidence for phonological recoding can be inferred when homophone foils and pseudohomophones either facilitate or hinder task performance depending upon the nature of the experimental task. However, these behavioural tasks are limited in terms of their ability to provide insight into the on-line processes involved in word identification. For this reason ERPs, which provide insight into the on-line processes involved in language, were used to investigate the influence of phonology during sentence reading.

Non-word stimuli that were homophonic with either homophone pairs (PSEUDOFOIL-HOMOPHONE) or with non-homophonic words (PSEUDOFOIL-NONHOMOPHONE) were used as sentence completions in Experiment 4. The results of this study showed that both types of pseudohomophones produced N400 amplitudes that were significantly smaller from those produced by incongruous sentence-ending words that were phonologically unexpected. However, the N400 amplitudes that were associated with the pseudohomophones did not differ from those associated with the phonologically expected homophone foils, which were also incongruous, in the FOIL condition. The reduced N400 amplitudes that were associated with the pseudohomophones was interpreted as evidence for phonological recoding.

This finding is consistent with the predictions made by the dual-route model. Presumably, the pseudohomophones were processed through the non-lexical route. According to the model, the orthographic representations that were associated with the pseudohomophones activated the corresponding phonological representations for these stimuli. Inasmuch as the phonological codes associated with the pseudohomophones were shared with real English words these representations were able to activate the stored lexical representations for the semantically appropriate terminal words for the sentences. The use of phonological codes during sentence reading influenced the elicitation of the N400 response.

Although these findings are consistent with the predictions of the dual-route model other findings from the present research which support phonological recoding are not. Most of the experiments reported here showed that semantically incongruous homophone foils that were phonologically expected produced significantly smaller N400 amplitudes than did terminal words that were phonologically unexpected. This finding showed that the N400 responded differentially to semantically incongruous stimuli depending upon whether they were phonologically expected. These results indicate that the phonological codes associated with the homophone foils influenced the word identification process.

According to the dual-route model, familiar words are identified through the lexical route. The homophone foils that were used to complete the sentences incongruously in the present research were common English words that were familiar to the participants[5]. Inasmuch as the reduced N400 amplitudes observed to the FOIL condition were not attributable to orthographic similarity the most likely explanation for this effect is that phonological codes influenced the word identification process. However, the evidence for phonological recoding could not,

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[5]The level of familiarity was not manipulated in the present research. However, none of the subjects indicated that they were unfamiliar with any of the sentence-ending words. Further, the results of the pilot study performed by Forbes (1993) that determined the spelling frequency for each homophone in a homophone pair did not indicate that subjects were unfamiliar with any of the homophones that were used in the subsequent research. Finally, if the homophone foils were unfamiliar to the subjects they would have elicited a N400 response because the preceding sentence context would not have primed subjects to expect unfamiliar words to occur. This situation would work against the prediction that phonological codes would influence the word identification process inasmuch as unprimed sentence-ending words have been demonstrated to reliably elicit a N400 response (Kutas & Van Petten, 1988). Thus, the reduced N400 amplitudes that were observed throughout most of the present research to the FOIL condition suggests that subjects were familiar with the homophone foils and that phonological recoding occurred.

according to the model, have occurred through the use of the lexical route since this route does not propose a role for phonological influences.

An alternative explanation for this finding is that the homophone foils were identified through the non-lexical route. Inasmuch as the lexical and non-lexical routes are presumed to operate in parallel it is possible that the orthographic representations associated with the homophone foils activated the corresponding phonological representations which in turn activated the lexical representations associated with the semantically appropriate homophones. Thus, this explanation proposes that the homophone foils and pseudohomophones were processed through the same route. While this explanation can account for how the phonological codes associated with these lexical and non-lexical stimuli, respectively, influenced the word identification process it is inconsistent with the predictions of the dual-route model which proposes that word identification for lexical and non-lexical stimuli proceeds through separate routes.

In contrast, an alternative approach to word identification has been proposed by interactive models of visual word recognition which propose that word identification occurs through a single processing route (e.g. Seidenberg & McClelland, 1989; Van Orden et al., 1990; O'Seaghdha & Marin, 1997). The interactive model of word recognition that has received the most attention by researchers was developed by Seidenberg and McClelland (1989). This model depicts the processes involved in visual word recognition as involving three types of codes: orthographic, phonological and semantic. Words are held to be represented in memory using these three types of codes, and these codes interact with each other at various points in the word recognition process. Each word is associated with a pattern of activation that reflects the orthographic, phonological and semantic representations.

The basic assumption of this model is that the pattern of activation that is associated with any one type of code can be altered by the input activation of other codes. In addition, this model does not presume that lexical and non-lexical stimuli are processed differently. The results of the present research provide support for this model. As indicated previously, the goal of the present research was to investigate the use of phonological codes during silent reading and the experimental factors that have been shown in behavioural research to influence to use of phonologically based strategies during word identification. This investigation showed that the importance of phonological codes can be diminished by manipulating task requirements.

The results of Experiment 1 showed that the importance of phonological codes was reduced during sentence reading when subjects were required to perform a semantic judgement task. Presumably, the use of the semantic judgement task in this experiment forced subjects to attend to the orthographic representations of the sentence-ending words in order to optimize their task performance. In contrast to Forbes (1993) which required subjects to simply read the sentences the results of Experiment 1 showed that phonological codes associated with the homophone foils did not overshadow the effect of violating the semantic expectancy that was primed by the preceding sentence context. This finding is consistent with the model proposed by Seidenberg and McClelland (1989) inasmuch as the importance of the phonological codes during reading was altered by the use of the semantic judgement task.

Similar results were observed when pronounceable non-word stimuli (both non-pseudohomophones and pseudohomophones) were included in the stimulus sets used in Experiments 3 and 4, respectively. Unlike Experiment 1 these experiments required that subjects simply read the sentences. However, the results of these experiments showed that the importance of phonological codes was reduced in comparison to the results reported in Experiment 2 and by Forbes (1993). The findings from Experiments 3 and 4 supported previous behavioural studies which have indicated that the inclusion of non-word stimuli can influence the degree to which phonological codes influence the word identification process (McNamara & Healy, 1988). These findings provide evidence supporting the position that the importance of phonological codes during word identification can be altered by task requirements. Thus, these results are consistent with the prediction that the importance of a particular code during word identification can be influenced by the use of other codes.

Overall, the present results are more in line with the basic assumption associated with the interactive model and suggest that the importance of the orthographic, phonological and semantic codes can be manipulated. This position gains some support from the data associated with the N270 component. As discussed previously, evidence was obtained in Experiment 2 and Forbes (1993) which indicated that the N270 component was sensitive to deviations in orthographic expectancy for the sentence-ending words. Similar findings were reported by Connolly et al., (1995) in a sentence reading task. In contrast, the N400 component responds reliably to semantically unprimed words and was sensitive to the phonological representations of stimuli. Taken together, these findings suggest that orthographic, phonological and semantic codes operate independently from each other. However, since the N270 component did not respond reliably to deviations in orthographic expectancy throughout the present research further investigation will be required in order to verify this claim.

Research Limitations and Directions for Future Research

The present series of studies provided evidence supporting phonological recoding during the reading of sentences. In addition, this research also showed that the importance of phonological codes can be diminished through the manipulation of task requirements. However, as with all research there are limitations to the insight that these data can provide into the subtle processes involved in language.

One limitation of the present data concerns the differences in ERP patterns that were observed between the experiments. The results of Experiment 1 showed that the inclusion of a semantic judgement task reduced the importance of phonological codes during reading. Similarly, the inclusion of non-word stimuli in the stimulus sets presented in Experiments 3 and 4 reduced the importance of the phonological factors that appeared to be important in Forbes (1993) and Experiment 2. Evidence that these manipulations reduced the importance of phonological codes during word identification was obtained from the N400 amplitude data. The N400 amplitudes that were associated with the FOIL condition in Experiment 1, which used the semantic judgement task, were significantly larger than the amplitudes that were associated with the CONGRUENT condition. The same pattern of ERPs was observed in Experiments 3 and 4 which used the non-word stimuli as sentence completions.

These results were interpreted as evidence that the importance of phonological codes during reading was reduced in comparison to the results of Experiment 2 and Forbes (1993). That is, the results of Experiment 2 and Forbes (1993) showed that the N400 amplitudes that were associated with the FOIL and CONGRUENT conditions did not differ from each other. The absence of a difference between these conditions was interpreted as evidence that the phonological codes overshadowed the effect of the semantic violation produced by the incongruous terminal words of the sentences.

These results indicate that the stimulus conditions produced different patterns of ERP responses depending upon the level of importance that phonological factors played during sentence reading. Inasmuch as the differences between the stimulus conditions within each experiment are statistically reliable it is conceivable that the differences in the patterns of ERP responses that were observed between the experiments could also be statistically reliable. If the differences in the patterns of ERPs that were observed between the experiments were statistically reliable this finding would provide further support for the position that manipulations in task requirements diminished the importance of phonological factors.

Inasmuch as the present research and behavioural research suggests that subtle changes in task requirements may alter the importance of phonological codes during word identification it is reasonable to presume that differences in ERP patterns between experiments may be due to the semantic judgement task and non-words. However, this issue can not be addressed by .a that were obtained from this series of experiments because different groups of subjects used during each of the experiments that were conducted in this series. The use of different ject pools may be problematic since neural responses that are associated with the individual ojects within a single experiment have been observed to vary greatly in amplitude.

As mentioned previously, the individual waveforms that were observed in Experiment 3 showed that some subjects appeared to elicit a N400 response to the FOIL condition that was similar in amplitude to the N400 elicited by semantically incongruous stimuli that were phonologically unexpected. Despite this observation the overall finding was that the N400 amplitudes that were associated with the FOIL condition were significantly smaller than those associated with the semantically incongruous stimuli that were phonologically unexpected. Thus, subjects within a single experiment can elicit different patterns of ERPs to the same stimuli. This individual variation in N400 amplitude may be problematic for interpreting whether the differences in ERP patterns observed between experiments are due to the experimental manipulation or to the variability associated with the individual subjects. However, it is possible to investigate whether the differences in ERP patterns that are observed between the experiments are due to manipulations in task requirements.

A second limitation of the present data is concerned with the use of highly contextually constrained sentences. As indicated previously, a high level of contextual constraint makes the terminal words of sentences extremely predictable (Shannon, 1948; Taylor, 1953; Bloom & Fischler, 1980). Inasmuch as the typical reading material to which people are exposed does not consist of sentences with predictable terminal words this manipulation may be somewhat artificial. Previous research conducted by Daneman and Stainton (1991) only provided evidence for phonological recoding during the reading of text when subjects were previously exposed to an error free version of the passage. Insofar as this prior exposure familiarized the subjects with the passage of text it could be argued that reading an error free version of the passage prior to performing their task resulted in priming. It is possible that evidence for phonological recoding was obtained because subjects were primed, both semantically and phonologically, to receive certain words.

A similar claim can be made with regard to the present research inasmuch as the high level of contextual constraint primed subjects to expect a particular terminal word. Thus, it is possible that the evidence for phonological recoding is limited to situations where subjects can expect words with particular phonological representations. This issue can be investigated in future research by manipulating the level of contextual constraint of the sentences that are completed with homophone foils. Evidence for phonological recoding in this instance would provide further support for the position that phonological codes assume a critical role in the processes involved in word identification.

Summary

This series of experiments was designed to investigate whether phonological recoding occurs during silent reading using ERPs. Overall, these studies provide confirm and extend behavioural research and provide support for phonological recoding. This research also demonstrates that manipulations in task requirements can influence the importance of phonological factors during sentence reading. In addition, the present results indicate that the N400 response is a unique neural component that reflects violations in semantic priming and provides a useful tool for investigating phonological influences during reading.

APPENDIX A

Table A1

Homophone Spelling Norms

The following homophone pairs were used to complete sentences in the CONGRUENT and FOIL conditions in Experiment 1. The spelling proportions (PROP) represent the spelling frequency for the homophones within a homophone pair when they were orally presented in the absence of any context. Homophones spelled most frequently are referred to as high spelling frequency (HSF) whereas, those spelled least frequently are referred to as low spelling frequency (LSF).

HSF	Proportion	LSF	Proportion
base	0.98	bass	0.02
bell	1.00	belle	0.00
wood	0.92	would	0.08
air	0.96	heir	0.00
hair	0.87	hare	0.13
bear	0.76	bare	0.24
beat	0.67	beet	0.33
fair	0.88	fare	0.12
gate	0.88	gait	0.12
poor	0.67	pour	0.27
pray	0.90	prey	0.10
pain	0.98	pane	0.02

APPENDIX A

Table A1 con't

rain	0.98	reign	0.02
pole	0.82	poll	0.16
real	0.80	reel	0.20
fairy	0.75	ferry	0.23
one	0.84	won	0.16
bail	0.73	bale	0.27
toe	0.96	tow	0.04
peak	0.67	peek	0.33
sun	0.88	son	0.12
heal	0.63	heel	0.37
night	0.69	knight	0.29
eye	0.78	I	0.22
sail	0.76	sale	0.24
him	0.69	hymn	0.29
plane	0.65	plain	0.35
know	0.65	no	0.35
nun	0.69	none	0.31
peace	0.65	piece	0.33
stair	0.61	stare	0.39
pale	0.80	pail	0.20
steal	0.61	steel	0.39

APPENDIX A

Table A1 con't

sell	0.78	cell	0.22
ate	0.77	eight	0.23
male	0.65	mail	0.35
tail	0.63	tale	0.37
course	0.88	coarse	0.12
seem	0.75	seam	0.25
feet	0.87	feat	0.13
seen	0.91	scene	0.09
steak	0.61	stake	0.39
bore	0.61	boar	0.35
break	0.71	brake	0.29
flower	0.79	flour	0.21
symbol	0.98	cymbal	0.02
bow	0.96	beau	0.04
axe	0.98	acts	0.02
allowed	0.84	aloud	0.10
band	0.83	banned	0.17
bee	0.84	be	0.14
blue	0.96	blew	0.04
bread	0.92	bred	0.06
sense	0.66	cents	0.18

APPENDIX A

Table A1 con't

doe	0.70	dough	0.22
you	0.86	ewe	0.12
guest	0.96	guessed	0.02
heard	0.84	herd	0.14
hire	0.68	higher	0.28
horse	0.88	hoarse	0.10
new	0.73	knew	0.27
not	0.66	knot	0.24
nose	0.88	knows	0.10
mayor	0.73	mare	0.27
mist	0.65	missed	0.35
past	0.80	passed	0.20
prince	0.67	prints	0.25
rose	0.96	rows	0.04
root	0.78	route	0.22
sweet	0.90	suite	0.10
sight	0.76	site	0.24
thrown	0.74	throne	0.24
graft	0.80	graphed	0.16
choose	0.84	chews	0.10
hole	0.62	whole	0.38

APPENDIX A

Table A1 con't

wear	0.63	where	0.37

APPENDIX A

Table A2

Sentence stimuli used in Experiment 1.

Terminal words for the following sentences were manipulated in Experiment 1. All high cloze probability words for the sentences are homophones. Terminal words for these sentences were manipulated to make the CONGRUENT and FOIL conditions. These sentences were normed using a pool of 40 subjects. The proportion of subjects that completed each of the sentences during the pilot study with the semantically appropriate homophone is presented in parenthesis.

1.	(.85)	The manager phoned the applicant that he decided to hire.
	(.55)	To reach the mountain top Phil had to climb a little bit higher.
2.	(.95)	The boxing match started at the sound of the bell.
	(.85)	Scarlet O'Hara was a southern belle.
3.	(1.00)	Oak and mahogany are both expensive types of wood.
	(.50)	When the lawyer asked her to testify Nancy said she would.
4.	(1.00)	The little girl has long brown hair.
	(.95)	The teacher told her class a story about a tortoise and a hare.
5.	(1.00)	That large brown animal is a grizzly bear.
	(.95)	Old Mother Hubbard's cupboards were bare.
6.	(.70)	Rock music has a strong beat.
	(.50)	A purple vegetable that is often pickled is the beet.

APPENDIX A

Table A2 con't

7.	(.95)	Karen went on the ferris wheel at the country fair.
	(.90)	Cindy took out enough money for bus fare.
8.	(.85)	When he gets to the end of the walk he must open the gate.
	(.40)	The child walked with an awkward gait.
9.	(.95)	The article discussed the inequality between the rich and the poor.
	(.85)	The cement was mixed and ready to pour.
10.	(.95)	The congregation kneeled down to pray.
	(.90)	Hawks and eagles are birds of prey.
11.	(.95)	The patient was given medicine to ease her pain.
	(.80)	The children broke the neighbour's window pane.
12.	(1.00)	The picnic was cancelled when it began to rain.
	(.90)	The king's death ended his long reign.
13.	(1.00)	The worker climbed up the telephone pole.
	(.95)	Eight hundred people were surveyed in a Gallup poll.
14.	(.90)	The figures in the wax museum looked very real.
	(.55)	Jason bought a fishing rod and reel.
15.	(1.00)	Billy put his tooth under his pillow for the tooth fairy.
	(.95)	Julie took her car over to PEI on the ferry.
16.	(1.00)	Four minus three equals one.

APPENDIX A

Table A2 con't

	(.20)	After losing five consecutive games the tennis player finally won.
17.	(.80)	To keep the boat from sinking the man had to bail.
	(.60)	The farmer stacked the last hay bale.
18.	(.75)	Janice went outside to get some fresh air.
	(.75)	A person who inherits a family fortune is called an heir.
19.	(.90)	The highest part of the mountain is the peak.
	(.35)	The curious child opened the bag to take a peek.
20.	(.75)	The planets circle the sun.
	(.90)	Ned has a daughter and a son.
21.	(1.00)	A yellow and black striped insect that stings is called a honey bee.
	(.65)	Tracy will meet us after the show if we tell her how long we will be.
22.	(.95)	The soldier's wounds took a long time to heal.
	(. 75)	Tina's dress shoe has a broken heel.
23.	(1.00)	It is easiest to view the stars at night.
	(.35)	Sleeping Beauty was rescued by a white knight.
24.	(.95)	The pirate wore a patch over his eye.
	(.70)	George wants to go to the movie and so do I.
25.	(1.00)	Tomorrow the ship will set sail.

APPENDIX A

Table A2 con't

	(.95)	The store was having a closing out sale.
26.	(.90)	The woman identified the man when she was shown a picture of him.
	(.70)	The congregation sang a hymn.
27.	(.70)	The fact that the Canadian flag is red and white is something that most people know.
	(1.00)	The answer to the question was either yes or no.
28.	(1.00)	Susan joined a convent and became a nun.
	(.90)	Bill went to the store for eggs but there were none.
29.	(.95)	The dove is a sign of peace.
	(.95)	The class baked a cake and everyone had a piece.
30.	(.95)	To hide the treasure the pirates dug a deep hole.
	(.95)	The sum of all the parts equals a whole.
31.	(.70)	While going up to his bedroom Jim tripped on the top stair.
	(.70)	The woman's actions were so odd that people stopped to stare.
32.	(.75)	Before fainting the woman's face became very pale.
	(.85)	Donna built a sandcastle with her shovel and pail.
33.	(1.00)	The man wanted the game tickets so much he was prepared to beg, borrow or steal.

APPENDIX A

Table A2 con't

	(.95)	The cutlery is made from stainless steel.
34.	(.85)	The real estate agent had two houses left to sell.
	(.85)	The prisoner had a sink in his cell.
35.	(.95)	They did the dishes after they ate.
	(.85)	The number of legs a spider has is eight.
36.	(1.00)	Of the six kittens half were female and half were male.
	(.90)	Each day the postman delivered Mary's mail.
37.	(1.00)	The dog wagged its tail.
	(1.00)	The campers listened to their leader tell an old wives' tale.
38.	(.90)	Ray ran the obstacle course.
	(.70)	Table salt is fine grained but rock salt is coarse.
39.	(.75)	Tedious classes are often shorter than they seem.
	(.80)	When Gerald bent over his pants ripped along the seam.
40.	(1.00)	The shoes were too small for Mike's feet.
	(.35)	Winning a gold medal is quite a feat.
41.	(1.00)	Tommy searched the park where his puppy was last seen.
	(.95)	When the couple started to argue in the restaurant they created a scene.
42.	(1.00)	The man ordered a T-bone steak.
	(.95)	Witches were burned at the stake.

APPENDIX A

Table A2 con't

43.	(.80)	The long math lecture was such a bore.
	(1.00)	A wild pig is also called a boar.
44.	(.95)	The secretary went for her coffee break.
	(.80)	The cyclist stopped his bike using only his front brake.
45.	(1.00)	The daisy is a very pretty flower.
	(1.00)	The baker was covered in white flour.
46.	(.65)	The maple leaf is a well known national symbol.
	(.85)	At the end of a drumroll the drummer usually hits a cymbal.
47.	(.80)	The present had a big red bow.
	(55)	A long time ago a woman's suitor was called a beau.
48.	(1.00)	Don chopped down the tree with an axe.
	(.80)	The play has three acts.
49.	(.95)	The player ran to first base.
	(1.00)	Sam adjusted the sound of the stereo using the treble and the bass.
50.	(1.00)	Harold plays the tuba in a marching band.
	(.45)	Smoking in most buildings has now been banned.
51.	(.95)	Baby boys are often dressed in the colour blue.
	(.90)	The tree broke when the strong wind blew.
52.	(1.00)	The baker baked a dozen loaves of bread.

APPENDIX A

Table A2 con't

	(.95)	The puppy was so expensive because it was pure bred.
53.	(.95)	A female deer is called a doe.
	(.90)	The baker rolled out the cookie dough.
54.	(.95)	Your mother told me to ask you.
	(.65)	A female sheep is called a ewe.
55.	(.95)	Sally flew to her destination in a small plane.
	(1.00)	Yoghurt is sold either with fruit or it is just plain.
56.	(.80)	Mother put out clean towels for the house guest.
	(.90)	Mel was unsure of the answer so he just guessed.
57.	(.90)	Sara speaks loudly so that she is heard.
	(.35)	The cattle farmer tended to the herd.
58.	(1.00)	Kevin's car was brand new.
	(.55)	Martha decided to tell Jane the story but Jane already knew.
59.	(1.00)	Sam asked if Lucy wanted to go but she did not.
	(.90)	The sailor learned how to tie a knot.
60.	(1.00)	The sick child has a runny nose.
	(.95)	We are unsure of the meeting time so let's ask Paula if she knows.
61.	(.80)	The townspeople voted to elect a mayor.
	(.50)	There is a children's song about an old grey mare.

APPENDIX A

Table A2 con't

62.	(.62)	The plants were sprayed using a very fine mist.
	(1.00)	Paul aimed his dart at the target but he missed.
63.	(1.00)	Fortune tellers talk about the present, future and past.
	(.80)	Kim thought she failed the test but later learned she had passed.
64.	(.95)	When the princess kissed the frog it turned into a prince.
	(.95)	When Marie got her film developed she ordered a second set of prints.
65.	(1.00)	He gave his fiancee a long-stemmed rose.
	(.90)	In class the students sat in the first two rows.
66.	(.90)	The part of a plant covered with soil is called the root.
	(1.00)	Leigh gets off at the next stop on the bus route.
67.	(1.00)	Sugar tastes very sweet.
	(1.00)	The newlyweds stayed in the honeymoon suite.
68.	(1.00)	She fell off the galloping horse.
	(.75)	The man talked so much that his voice went hoarse.
69.	(.90)	After surgery the blind man regained his sight.
	(.70)	The tour guide showed the group a famous historical site.
70.	(.90)	The athlete threw the shotput the farthest it had ever been thrown.
	(.85)	The king sat down on the royal throne.

APPENDIX A

Table A2 con't

71.	(.90)	The plastic surgeon completed the skin graft.
	(.40)	All the data points were plotted and graphed.
72.	(.95)	Colleen bought an outfit to wear.
	(1.00)	Lori remembered she had to meet her friend but she forgot when and where.
73.	(.80)	Michael chose the movie today and tomorrow Jane will get to choose.
	(.95)	Tobacco and bubble gum are things a pitcher usually chews.
74.	(.95)	Looking both ways before we cross the street is just a matter of common sense.
	(1.00)	Using a pay phone to make a call costs twenty-five cents.
75.	(.95)	If the children want to go they must ask their parents if they are allowed.
	(.50)	The child stood before the class and said the poem aloud.
76.	(.95)	Fred stubbed his big toe.
	(.95)	When Jim's car went into the ditch he called a garage to get a tow.

APPENDIX B

Table B1

ANOVA for N270 Amplitude Data for Condition X Site Analysis for Experiment 1

Source	df	MSE	F
Condition	2, 22	49.59	10.24*
Frequency	1, 11	21.21	1.99
Site	14, 154	9.24	2.19
Condition X Frequency	2, 22	33.72	1.80
Condition X Site	28, 308	1.59	2.73*
Normalized	28, 308	1.06	1.12
Frequency X Site	14, 154	1.28	1.96
Condition X Frequency X Site	28, 308	1.43	0.77

* $p < .05$

APPENDIX B

Table B2

Mean amplitudes (in µV) (and Standard Deviations) for the N270 and N400 components in Experiment 1

	N270	N400
Stimulus Conditions		
CONGRUENT	-0.79 (2.71)	-0.45 (2.08)
FOIL	-1.44 (2.20)	-1.33 (2.04)
INCONGRUENT	-3.10 (2.72)	-1.98 (2.36)

APPENDIX B

Table B3

ANOVA for N270 Amplitude Data for Condition X Region X Hemisphere Analysis for Experiment 1

Source	df	MSE	F
Condition	2, 22	13.15	9.86*
Region	3, 33	5.64	1.05
Hemisphere	1, 11	8.06	4.31
Condition X Region	6, 66	0.96	3.38*
Normalized	6, 66	0.74	1.42
Condition X Hemisphere	2, 22	1.17	0.80
Region X Hemisphere	3, 33	0.86	4.98*
Condition X Region X Hemisphere	6, 66	0.20	1.28

* $p < .05$

APPENDIX B

Table B4

Mean Amplitudes (in µV) (and Standard Deviations) for the Condition X Region X Hemisphere analysis for the N270 component in Experiment 1

Left Hemisphere				
	Frontal	Central	Temporal	Parietal
Congruent	-0.92 (2.11)	-1.15 (2.71)	-1.68 (1.97)	-0.90 (2.72)
Foil	-1.09 (1.39)	-1.99 (1.67)	-2.53 (1.52)	-1.66 (2.01)
Incongruent	-2.87 (1.89)	-3.79 (2.31)	-3.20 (1.69)	-3.18 (2.32)

Right Hemisphere				
	Frontal	Central	Temporal	Parietal
Congruent	-0.72 (2.16)	-0.64 (2.58)	-0.33 (1.59)	0.14 (2.55)
Foil	-0.46 (2.27)	-1.40 (1.19)	-1.00 (1.21)	-1.04 (1.71)
Incongruent	-2.98 (2.62)	-3.67 (2.80)	-2.08 (1.82)	-2.43 (2.59)

APPENDIX B

Table B5
ANOVA for N400 Amplitude Data for Condition X Site Analysis for Experiment 1

Source	df	MSE	F
Condition	2, 22	26.86	7.94*
Frequency	1, 11	29.90	0.20
Site	14, 154	5.28	3.01*
Condition X Frequency	2, 22	26.28	0.86
Condition X Site	28, 308	1.57	1.55
Frequency X Site	14, 154	1.40	0.47
Condition X Frequency X Site	28, 308	1.12	1.11

* $p < .05$

APPENDIX B

Table B6

Mean N400 Amplitudes (in µV) (and Standard Deviations) for the main effect for Site factor for Experiment 1

Sites	
Fz	-0.54 (2.59)
F3	-0.74 (2.39)
F4	-1.02 (2.40)
F7	-0.76 (1.82)
F8	-0.97 (1.89)
Cz	-1.51 (2.73)
C3	-1.03 (2.45)
C4	-1.53 (2.32)
Pz	-2.18 (2.42)
P3	-1.63 (2.37)
P4	-1.95 (2.10)
T3	-0.86 (1.76)
T4	-1.44 (1.52)
T5	-1.14 (2.02)
T6	-1.51 (2.13)

APPENDIX B

Table B7

ANOVA for N400 Amplitude Data for Condition X Region X Hemisphere Analysis for Experiment 1

Source	df	MSE	F
Condition	2, 22	7.45	7.79*
Region	3, 33	2.78	3.91*
Hemisphere	1, 11	5.08	2.34
Condition X Region	6, 66	0.96	1.91
Condition X Hemisphere	2, 22	1.43	0.07
Region X Hemisphere	3, 33	0.46	0.32
Condition X Region X Hemisphere	6, 66	0.22	0.82

* $p < .05$

APPENDIX B

Table B8

Mean N400 amplitudes (in μV) (and Standard Deviations) for main effect for Region factor - for Experiment 1

Region	
Frontal	-0.85 (1.74)
Central	-1.28 (1.99)
Temporal	-1.24 (1.44)
Parietal	-1.79 (1.94)

APPENDIX B

Table B9

ANOVA for accuracy data from semantic judgement task for Experiment 1

Source	df	MSE	F
Condition	2, 16	3.01	6.72*
Frequency	1, 8	2.13	0.08
Condition X Frequency	2, 16	1.69	3.65*

* $p < .05$

APPENDIX B

Table B10

Mean frequencies (and Standard Deviations) for accuracy data from semantic judgement task for main effect for Condition factor in Experiment 1

Stimulus Conditions	
CONGRUENT	16.89 (2.62)
FOIL	17.28 (1.58)
INCONGRUENT	18.89 (0.22)

APPENDIX B

Table B11

ANOVA for latency data from semantic judgement task for Experiment 1

Source	df	MSE	F
Condition	2, 16	0.02	5.87*
Frequency	1, 8	0.00	0.56
Condition X Frequency	2, 16	0.01	4.28*

* $p < .05$

APPENDIX B

Table B12

Means (and Standard Deviations) for latency data from semantic judgement task for main effect for Condition factor in Experiment 1

Stimulus Conditions	
CONGRUENT	1106 ms (0.26)
FOIL	1079 ms (0.20)
INCONGRUENT	970 ms (0.20)

APPENDIX C

Sentence stimuli used in Experiment 2

The sentences that were associated with each homophone pair and the corresponding ORTHOGRAPHICALLY SIMILAR (i.e., OS) and DISSIMILAR (i.e., OD) words are presented together. The sentences for which the OS and OD words had high cloze probability were used in the RELATED FILLERS (RF) condition only when these words (i.e., OS and OD) were not being used as terminal words for the homophone sentences. The level of cloze probability for each sentence is indicated in brackets. Sentences for which homophones were terminal words were normed on 40 subjects. Other sentences were normed on 23 subjects.

1.	(.95)	The player ran to first base.
	(1.00)	Sam adjusted the sound of the stereo using the treble and the bass.
	(1.00)	After a stressful day Joan relaxed in a bubble bath.
	(.96)	The sad movie made the woman cry.
2.	(1.00)	The little girl has long brown hair.
	(.95)	The teacher told her class a story about a tortoise and a hare.
	(1.00)	Larry writes with his left hand.
	(1.00)	Jeff dug the prize out of the cereal box.
3.	(1.00)	That large brown animal is a grizzly bear.
	(.95)	Old Mother Hubbard's cupboards were bare.
	(1.00)	At night the farm animals slept inside the barn.
	(1.00)	Michelle stirred the sauce with a wooden spoon.
4.	(.95)	Karen went on the ferris wheel at the country fair.
	(.90)	Cindy took out enough money for bus fare.
	(.88)	The campers cooked dinner over an open fire.
	(1.00)	She swept the porch with a broom.

APPENDIX C

5.	(.95)	The article discussed the inequality between the rich and the poor.
	(.85)	The cement was mixed and ready to pour.
	(1.00)	Jason slipped on the banana peel.
	(1.00)	Jason lost his driver's license.
6.	(.95)	The congregation kneeled down to pray.
	(.90)	Hawks and eagles are birds of prey.
	(1.00)	The children went outside to play.
	(1.00)	Paddy cut the fabric with a pair of scissors.
7.	(.95)	The patient was given medicine to ease her pain.
	(.80)	The children broke the neighbour's window pane.
	(1.00)	Grandpa likes to smoke a corn-cob pipe.
	(1.00)	The soccer players ran out on the playing field.
8.	(1.00)	The worker climbed up the telephone pole.
	(.95)	Eight hundred people were surveyed in a Gallup poll.
	(1.00)	Jeff dived into his neighbour's swimming pool.
	(1.00)	Mike washed the car with soap and water.
9.	(1.00)	Billy put his tooth under his pillow for the tooth fairy.
	(.95)	Julie took her car over to PEI on the ferry.
	(1.00)	The comedian's joke was really funny.
	(1.00)	Grandma baked an apple pie.
10.	(.95)	Fred stubbed his big toe.
	(.95)	When Jim's car went into the ditch he called a garage to get a tow.
	(1.00)	Eight plus two equals ten.
	(1.00)	John sliced the tomato with a knife.

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11.	(.75)	The planets circle the sun.
	(.85)	Ned has a daughter and a son.
	(1.00)	The ship went out to sea.
	(1.00)	Jenny played volleyball on the sandy beach.
12.	(.95)	The long math lecture was such a bore.
	(.75)	A wild pig is also called a boar.
	(.96)	Joan sang a lullaby to her newborn baby.
	(1.00)	Jan planted vegetables in her garden.
13.	(1.00)	Tomorrow the ship will set sail.
	(.95)	The shop was having a closing-out sale.
	(1.00)	The man asked the waiter for pepper salt.
	(1.00)	The answer to the question was either true or false.
14.	(.95)	Sally flew to her destination in a small plane.
	(1.00)	Yoghurt is sold either with fruit or it is just plain.
	(1.00)	The pirates made the man walk the gang plank.
	(1.00)	Mom made some chicken noodle soup.
15.	(.95)	The dove is a sign of peace.
	(.95)	The class baked a cake and everyone had a piece.
	(1.00)	Greg wrote the note on the pad of paper.
	(1.00)	The police officer gave Jack a speeding ticket.
16.	(.75)	Before fainting the woman's face became very pale.
	(.85)	Donna built a sandcastle with her shovel and pail.
	(.79)	Mary raked the autumn leaves into a large pile.
	(1.00)	Mike pointed to the picture with his index finger.

APPENDIX C

17.	(1.00)	The man wanted the tickets so much he would beg, borrow or steal.
	(.95)	The cutlery is made from stainless steel.
	(1.00)	The children set up a lemonade stand.
	(1.00)	The tropical storm caused a tidal wave.
18.	(1.00)	Of the six kittens half were female and half were male.
	(.90)	Each day the postman delivered Mary's mail.
	(.96)	When the weather became warm the snow began to melt.
	(1.00)	Jenny's mother told her a bedtime story.
19.	(1.00)	The dog wagged its tail.
	(1.00)	The campers listened to their leader tell an old wives' tale.
	(1.00)	The children climbed the apple tree.
	(1.00)	Donna looked at her reflection in her mirror.
20.	(1.00)	The man ordered a T-bone steak.
	(.95)	Witches were burned at the stake.
	(1.00)	The laundry soap did not remove the coffee stain.
	(1.00)	The chicken laid an egg.
21.	(.95)	The secretary went for her coffee break.
	(.80)	The cyclist stopped his bike using only the front brake.
	(1.00)	Piano keys are white and black.
	(1.00)	Nancy saw a falling star and made a wish.
22.	(.95)	Little boys are often dressed in the colour blue.
	(.90)	The tree broke when the strong wind blew.
	(1.00)	Trish woke up when the dog started to bark.
	(1.00)	The artist mixed a new shade of red paint.

APPENDIX C

23.	(.95)	When the princess kissed the frog it turned into a prince.
	(.95)	When Marie got her film developed she ordered a second set of prints.
	(1.00)	The new shop promised to have lower prices.
	(1.00)	Janice knocked on her neighbour's front door.
24.	(1.00)	He gave his fiancee a long-stemmed rose.
	(.90)	In class the students sat in the first two rows.
	(1.00)	The hunters heard the lion's mighty roar.
	(1.00)	Tommy brought a present to his friends birthday party.
25.	(.90)	The athlete threw the shotput the farthest it had ever been thrown.
	(.85)	The king sat down on the royal throne.
	(1.00)	The singer had a bad case of strep throat.
	(1.00)	The kitten likes to drink milk.
26.	(.70)	While going up to his bedroom Jim tripped on the top stair.
	(.70)	The woman's actions were so odd that people stopped to stare.
	(1.00)	Donna bought bread at the corner store.
	(1.00)	She unlocked the car with a key.
27.	(1.00)	Chocolate tastes very sweet.
	(1.00)	The newlyweds stayed in the honeymoon suite.
	(1.00)	Many people drink coffee with cream and sugar.
	(.92)	The author finished the last chapter of his book.
28.	(.75)	Tedious classes are often shorted than they seem.
	(.80)	When Gerald bent over his pants ripped along the seam.
	(1.00)	The lifeguard taught the child to swim.
	(1.00)	Paul sat down to eat at the dinner table.

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29.	(.95)	The soldier's wounds took a long time to heal.
	(.75)	Tina's dress shoe has a broken heel.
	(.83)	Jane skied down the hill.
	(1.00)	The cat chased the little gray mouse.
30.	(.80)	The figures in the wax museum looked very real.
	(.55)	Jason bought a fishing rod and reel.
	(1.00)	Jeff answered the telephone when it rang.
	(1.00)	Ralph washed the kitchen floor with a mop.

APPENDIX D

Table D1

ANOVA for N270 Amplitude Data for Condition X Site Analysis for Experiment 2

Source	df	MSE	F
Condition	3, 57	71.55	3.68*
Site	14, 266	15.28	1.79
Condition X Site	42, 798	3.44	1.05

* $p < .05$

APPENDIX D

Table D2

Mean amplitudes (in μV) (and Standard Deviations) for the N270 and N400 components in Experiment 2

Stimulus Conditions	N270	N400
CONGRUENT	1.52 (4.13)	3.37 (4.17)
FOIL	0.39 (4.32)	2.44 (4.69)
OS	0.54 (4.11)	-0.20 (4.54)
OD	-0.76 (4.57)	-0.49 (5.34)

APPENDIX D

Table D3

ANOVA for N270 Amplitude Data for Condition X Region X Hemisphere Analysis for Experiment 2

Source	df	MSE	F
Condition	3, 57	37.88	3.68*
Region	3, 57	15.82	3.55*
Hemisphere	1, 19	27.45	0.51
Condition X Region	9, 171	3.61	0.85
Condition X Hemisphere	3, 57	4.41	0.86
Region X Hemisphere	3, 57	3.60	1.15
Condition X Region X Hemisphere	9, 171	0.90	1.27

* $p < .05$

APPENDIX D

Table D4

Mean amplitudes (in μV) (and Standard Deviations) for the main effect for Region for the N270 component in Experiment 2

Region	
Frontal	0.35 (3.73)
Central	0.89 (4.64)
Temporal	-0.19 (3.35)
Parietal	1.14 (4.54)

APPENDIX D

Table D5

ANOVA for N400 Amplitude Data for Condition X Site Analysis for Experiment 2

Source	df	MSE	F
Condition	3, 57	74.51	14.84**
Site	14, 266	20.44	2.56*
Condition X Site	42, 798	4.17	4.66**
Normalized	42, 798	5.45	3.59*

* $p < .05$; ** $p < .001$

APPENDIX D

Table D6

ANOVA for N400 Amplitude Data for Condition X Region X Hemisphere Analysis for Experiment 2

Source	df	MSE	F
Condition	3, 57	38.36	16.81**
Region	3, 57	24.88	3.28
Hemisphere	1, 19	20.62	0.08
Condition X Region	9, 171	4.24	7.70**
Normalized	9, 171	6.31	9.64**
Condition X Hemisphere	3, 57	6.02	3.26*
Normalized	3, 57	3.94	5.73*
Region X Hemisphere	3, 57	4.36	0.95
Condition X Region X Hemisphere	9, 171	1.06	1.17

* $p < .05$; ** $p < .001$

APPENDIX E

Table E1

Sentence stimuli used in Experiment 3

The sentences that were associated with each homophone pair and the corresponding ORTHOGRAPHICALLY SIMILAR (i.e., OS) and DISSIMILAR (i.e., OD) words are presented together. The sentences for which the OS and OD words had high cloze probability were used in the RELATED FILLER (RF) condition only when these words (i.e., OS and OD) were not being used as terminal words for the homophone sentences. The level of cloze probability for each sentence is indicated in brackets. Sentences for which homophones were terminal words were normed on 40 subjects. Other sentences were normed on 23 subjects.

1.	(.95)	The player ran to first base.
	(1.00)	Sam adjusted the sound of the stereo using the treble and the bass.
	(1.00)	After a stressful day Joan relaxed in a bubble bath.
	(.96)	The sad movie made the woman cry.
2.	(1.00)	The little girl has long brown hair.
	(.95)	The teacher told her class a story about a tortoise and a hare.
	(1.00)	Larry writes with his left hand.
	(1.00)	Jeff dug the prize out of the cereal box.
3.	(1.00)	That large brown animal is a grizzly bear.
	(.95)	Old Mother Hubbard's cupboards were bare.
	(1.00)	At night the farm animals slept inside the barn.
	(1.00)	Michelle stirred the sauce with a wooden spoon.

APPENDIX E

Table E1 con't

4.	(.95)	Karen went on the ferris wheel at the country fair.
	(.90)	Cindy took out enough money for bus fare.
	(.88)	The campers cooked dinner over an open fire.
	(1.00)	She swept the porch with a broom.
5.	(.95)	The article discussed the inequality between the rich and the poor.
	(.85)	The cement was mixed and ready to pour.
	(1.00)	Jason slipped on the banana peel.
	(1.00)	Jason lost his driver's license.
6.	(.95)	The congregation kneeled down to pray.
	(.90)	Hawks and eagles are birds of prey.
	(1.00)	Jeff dived into his neighbour's swimming pool.
	(.96)	The car ran out of gas.
7.	(.95)	The patient was given medicine to ease her pain.
	(.80)	The children broke the neighbour's window pane.
	(1.00)	Grandpa likes to smoke a corn-cob pipe.
	(1.00)	The soccer players ran out on the playing field.
8.	(1.00)	The worker climbed up the telephone pole.
	(.95)	Eight hundred people were surveyed in a Gallup poll.
	(1.00)	The children went outside to play.
	(1.00)	Mike washed the car with soap and water.

APPENDIX E

Table E1 con't

9.	(1.00)	Billy put his tooth under his pillow for the tooth fairy.
	(.95)	Julie took her car over to PEI on the ferry.
	(1.00)	The comedian's joke was really funny.
	(1.00)	Grandma baked an apple pie.
10.	(.95)	Fred stubbed his big toe.
	(.95)	When Jim's car went into the ditch he called a garage to get a tow.
	(1.00)	Eight plus two equals ten.
	(1.00)	John sliced the tomato with a knife.
11.	(.75)	The planets circle the sun.
	(.85)	Ned has a daughter and a son.
	(1.00)	The ship went out to sea.
	(1.00)	The exam had five multiple choice questions.
12.	(.95)	The long math lecture was such a bore.
	(.75)	A wild pig is also called a boar.
	(.96)	Joan sang a lullaby to her newborn baby.
	(1.00)	Jan planted vegetables in her garden.
13.	(1.00)	Tomorrow the ship will set sail.
	(.95)	The shop was having a closing-out sale.
	(1.00)	Mom made some chicken noodle soup.
	(1.00)	The answer to the question was either true or false.

APPENDIX E

Table E1 con't

14.	(.95)	Sally flew to her destination in a small plane.
	(1.00)	Yoghurt is sold either with fruit or it is just plain.
	(1.00)	Greg wrote the note on the pad of paper.
	(1.00)	The pot of gold is at the end of the rainbow.
15.	(.95)	The dove is a sign of peace.
	(.95)	The class baked a cake and everyone had a piece.
	(1.00)	The pirates made the man walk the gang plank.
	(1.00)	Mike pointed to the picture with his index finger.
16.	(.75)	Before fainting the woman's face became very pale.
	(.85)	Donna built a sandcastle with her shovel and pail.
	(.79)	Mary raked the autumn leaves into a large pile.
	(1.00)	The hockey player laced up his skates.
17.	(1.00)	The man wanted the tickets so much he would beg, borrow or steal.
	(.95)	The cutlery is made from stainless steel.
	(1.00)	The children set up a lemonade stand.
	(1.00)	The tropical storm caused a tidal wave.
18.	(1.00)	Of the six kittens half were female and half were male.
	(.90)	Each day the postman delivered Mary's mail.
	(.96)	When the weather became warm the snow began to melt.
	(1.00)	Jenny's mother told her a bedtime story.

APPENDIX E

Table E1 con't

19.	(1.00)	The dog wagged its tail.
	(1.00)	The campers listened to their leader tell an old wives' tale.
	(1.00)	The children climbed the apple tree.
	(1.00)	Donna looked at her reflection in her mirror.
20.	(1.00)	The man ordered a T-bone steak.
	(.95)	Witches were burned at the stake.
	(1.00)	The laundry soap did not remove the coffee stain.
	(1.00)	The chicken laid an egg.
21.	(.95)	The secretary went for her coffee break.
	(.80)	The cyclist stopped his bike using only the front brake.
	(1.00)	Piano keys are white and black.
	(1.00)	Nancy saw a falling star and made a wish.
22.	(.95)	Little boys are often dressed in the colour blue.
	(.90)	The tree broke when the strong wind blew.
	(1.00)	Trish woke up when the dog started to bark.
	(1.00)	The artist mixed a new shade of red paint.
23.	(.95)	When the princess kissed the frog it turned into a prince.
	(.95)	When Marie got her film developed she ordered a second set of prints.
	(1.00)	The new shop promised to have lower prices.
	(.96)	The lost motorist pulled over to ask for directions.

APPENDIX E

Table E1 con't

24.	(1.00)	He gave his fiancee a long-stemmed rose.
	(.90)	In class the students sat in the first two rows.
	(1.00)	The hunters heard the lion's mighty roar.
	(1.00)	Tommy brought a present to his friends birthday party.
25.	(.90)	The athlete threw the shotput the farthest it had ever been thrown.
	(.85)	The king sat down on the royal throne.
	(1.00)	The singer had a bad case of strep throat.
	(1.00)	The kitten likes to drink milk.
26.	(.70)	While going up to his bedroom Jim tripped on the top stair.
	(.70)	The woman's actions were so odd that people stopped to stare.
	(1.00)	Donna bought bread at the corner store.
	(1.00)	She unlocked the car with a key.
27.	(1.00)	Chocolate tastes very sweet.
	(1.00)	The newlyweds stayed in the honeymoon suite.
	(1.00)	Many people drink coffee with cream and sugar.
	(.77)	We found a bird's nest.
28.	(.75)	Tedious classes are often shorted than they seem.
	(.80)	When Gerald bent over his pants ripped along the seam.
	(1.00)	The lifeguard taught the child to swim.
	(.92)	The salad dressing was made with vinegar and oil.

APPENDIX E

Table E1 con't

29.	(.95)	The soldier's wounds took a long time to heal.
	(.75)	Tina's dress shoe has a broken heel.
	(.83)	Jane skied down the hill.
	(1.00)	The cat chased the little gray mouse.
30.	(.80)	The figures in the wax museum looked very real.
	(.55)	Jason bought a fishing rod and reel.
	(1.00)	Jeff answered the telephone when it rang.
	(1.00)	Ralph washed the kitchen floor with a mop.
31.	(.90)	Ray ran the obstacle course.
	(.70)	Table salt is fine grained but rock salt is coarse.
	(1.00)	The old ladies sat in their rocking chairs.
	(1.00)	Tim walked his dog on a leash.
32.	(.80)	To keep the boat from sinking Josh had to bail.
	(.60)	The farmer stacked the last hay bale.
	(.92)	The author finished the last chapter of his book.
	(1.00)	Many people eat peanut butter and jelly sandwiches.

APPENDIX E

Table E2

Non-word Stimuli used in Experiment 3

The non-word stimuli that were considered to be orthographically similar and dissimilar to the homophone pairs are presented below.

Homophone Pair	OS-NONWORD	OD-NONWORD
base/bass	bist	stalt
hair/hare	hoon	gop
bear/bare	blag	rekel
fair/fare	fost	trunt
poor/pour	pont	bollix
pray/prey	prok	corter
pain/pane	pult	lottal
pole/poll	pash	furrek
fairy/ferry	flirg	delp
toe/tow	tay	wolp
sun/son	sug	qualt
bore/boar	bint	glurt
sail/sale	stob	gorff
plane/plain	prain	hinner
peace/piece	paike	mamp
pale/pail	plin	grups
steal/steel	scult	thurny
male/mail	mirt	blint
tail/tale	tulf	finter
steak/stake	shamp	tulf
break/brake	blore	torm

APPENDIX E

Table E2 con't

blue/blew	bosk	wuggle
prince/prints	plaret	leet
rose/rows	roff	blogs
thrown/throne	tesner	keem
stair/stare	stome	dake
sweet/suite	shrat	rone
seem/seam	slig	roked
course/coarse	conder	hust
heal/heel	hote	lir
real/reel	rolt	keb
bail/bale	bewn	relten

APPENDIX E

Table E3

Additional sentences for the OS-WORD, OD-WORD, OS-NONWORD and OD-NONWORD stimulus conditions for Experiment 3

1.	(1.00)	The shoes were too small for Mike's feet.
2.	(.85)	When he gets to the end of the walk he must open the gate.
3.	(1.00)	The yellow part of an egg is called the yolk.
4.	(1.00)	The girls went to the shopping mall.
5.	(1.00)	The lady set up the ironing board.
6.	(1.00)	Tom bought a new soccer ball.
7.	(.83)	After the accident Helen's arm was very sore.
8.	(1.00)	Sharon tried on many shoes before she bought a pair.
9.	(1.00)	The dog is now full grown.
10.	(.70)	Rock music has a strong beat.
11.	(.90)	The top of the mountain is called the peak.
12.	(.80)	The basketball player pushed his opponent and got a foul.
13.	(.79)	Frank buttered his dinner roll.
14.	(1.00)	The dog whistle is too high for humans to hear.
15.	(.80)	Many people refuse to buy coats made from animal fur.
16.	(.71)	The young rockstar became a teenage idol.

APPENDIX F

Table F1

ANOVA for N270 Amplitude Data for Condition X Site Analysis for Experiment 3

Source	df	MSE	F
Condition	5, 75	132.26	8.49***
Site	14, 210	19.72	4.01*
Condition X Site	70, 1050	5.27	2.33*
Normalized	70, 1050	12.20	0.80

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX F

Table F2

Mean amplitudes (in μV) (and Standard Deviations) for the N270 and N400 components in Experiment 3

Stimulus Conditions	N270	N400
CONGRUENT	3.74 (5.11)	3.47 (4.20)
FOIL	2.57 (5.92)	1.27 (5.92)
OSW	-0.48 (5.09)	-2.20 (6.66)
ODW	-0.17 (5.56)	-1.38 (5.85)
OSN	-1.02 (4.77)	-2.57 (5.75)
ODN	-1.71 (4.43)	-1.36 (5.50)

APPENDIX F

Table F3

Mean N400 Amplitudes (in μV) (and Standard Deviations) for the main effect for Site factor for Experiment 3

Sites	
Fz	2.14 (5.77)
F3	1.56 (5.29)
F4	2.01 (5.77)
F7	0.12 (1.82)
F8	0.89 (4.18)
Cz	1.57 (7.05)
C3	1.24 (5.58)
C4	1.84 (6.64)
Pz	0.91 (6.97)
P3	1.14 (6.06)
P4	1.68 (5.91)
T3	-1.63 (3.96)
T4	0.29 (4.30)
T5	-0.07 (4.91)
T6	0.57 (5.03)

APPENDIX F

Table F4

ANOVA for N270 Amplitude Data for Condition X Region X Hemisphere Analysis for Experiment 3

Source	df	MSE	F
Condition	5, 75	72.54	8.08***
Region	3, 45	20.88	4.90*
Hemisphere	1, 15	14.32	6.38*
Condition X Region	15, 225	2.52	2.52*
Normalized	15, 225	9.67	0.29
Condition X Hemisphere	5, 75	7.70	2.70*
Normalized	5, 75	12.11	1.17
Region X Hemisphere	3, 45	6.11	1.03
Condition X Region X Hemisphere	15, 225	2.00	1.56

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX F

Table F5

Mean amplitudes (in μV) (and Standard Deviations) for the main effect for Region for the N270 component in Experiment 3

Region	
Frontal	1.15 (4.59)
Central	1.54 (6.13)
Temporal	-0.21 (4.30)
Parietal	1.41 (5.98)

APPENDIX F

Table F6

ANOVA for N400 Amplitude Data for Condition X Site Analysis for Experiment 3

Source	df	MSE	F
Condition	5, 75	131.65	10.05***
Site	14, 210	32.74	1.46
Condition X Site	70, 1050	6.01	2.39*
Normalized	70, 1050	8.46	1.28

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX F

Table F7

ANOVA for N400 Amplitude Data for Condition X Region X Hemisphere Analysis for Experiment 3

Source	df	MSE	F
Condition	5, 75	70.90	10.62***
Region	3, 45	34.78	1.37
Hemisphere	1, 15	25.89	0.01
Condition X Region	15, 225	6.38	3.27*
Normalized	15, 225	6.82	1.17
Condition X Hemisphere	5, 75	6.78	2.63
Region X Hemisphere	3, 45	9.06	0.26
Condition X Region X Hemisphere	15, 225	1.87	1.62

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX F

Table F8

ANOVA for N400 Latency Data for Condition X Site Analysis for Experiment 3

Source	df	MSE	F
Condition	5, 75	12933.82	3.82*
Site	14, 210	205.86	1.74
Condition X Site	70, 1050	113.50	1.64

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX F

Table F9

Mean Latencies (in ms) (and Standard Deviations) for the N400 component for the Condition x Site Analysis for Experiment 3

	Stimulus Conditions			
Sites	Congruent	Foil	OS-Word	OD-Word
Fz	426.63 (40.11)	415.64 (46.07)	396.08 (44.43)	402.19 (35.63)
F3	423.64 (43.69)	413.83 (45.79)	392.88 (46.40)	399.05 (34.94)
F4	422.66 (41.31)	413.75 (46.06)	398.46 (43.05)	402.60 (36.46)
F7	419.60 (40.49)	413.82 (45.71)	398.69 (44.90)	403.26 (34.23)
F8	421.42 (9.81)	414.68 (47.53)	408.38 (61.13)	401.42 (33.80)
Cz	426.10 (9.76)	413.67 (47.13)	393.75 (46.33)	402.23 (35.96)
C3	423.23 (10.56)	415.61 (49.01)	389.31 (46.03)	400.76 (35.95)
C4	427.30 (43.51)	415.96 (44.65)	391.34 (41.32)	402.46 (35.41)
Pz	425.49 (37.11)	414.43 (47.28)	393.09 (44.03)	404.54 (37.10)
P3	429.12 (39.24)	414.09 (49.86)	390.33 (45.81)	406.04 (36.80)
P4	422.91 (40.81)	416.98 (45.78)	392.21 (46.76)	403.82 (38.50)
T3	418.02 (40.83)	413.94 (54.11)	384.32 (40.75)	393.90 (33.58)
T4	423.64 (41.34)	412.65 (46.08)	395.88 (42.12)	405.76 (35.29)
T5	431.54 (40.15)	420.37 (55.18)	391.65 (42.25)	401.95 (38.75)
T6	429.49 (45.74)	418.79 (47.65)	394.49 (43.27)	405.43 (34.80)

APPENDIX F

Table F9 con't

	Stimulus Conditions	
Sites	OS-Nonword	OD-Nonword
Fz	391.89 (28.69)	391.84 (29.88)
F3	387.82 (29.26)	392.57 (30.19)
F4	391.68 (32.34)	391.43 (30.08)
F7	386.80 (30.33)	393.78 (27.74)
F8	389.45 (31.96)	389.93 (27.08)
Cz	385.89 (30.77)	393.26 (28.51)
C3	384.63 (33.93)	393.27 (29.28)
C4	388.69 (27.78)	389.83 (25.92)
Pz	386.74 (30.22)	391.29 (24.81)
P3	381.59 (31.03)	390.34 (23.76)
P4	391.47 (28.76)	391.58 (23.64)
T3	379.36 (25.75)	397.48 (31.82)
T4	392.58 (28.61)	389.55 (28.19)
T5	390.85 (26.61)	394.78 (25.40)
T6	396.16 (23.77)	393.50 (25.72)

APPENDIX F

Table F10

ANOVA for N400 Latency Data for Condition X Region X Hemisphere Analysis for Experiment 3

Source	df	MSE	F
Condition	5, 75	6867.78	3.97*
Region	3, 45	151.05	0.43
Hemisphere	1, 15	229.39	3.11
Condition X Region	15, 225	109.45	1.64
Condition X Hemisphere	5, 75	80.27	4.24*
Normalized	5, 75	23.06	4.78*
Region X Hemisphere	3, 45	114.25	0.37
Condition X Region X Hemisphere	15, 225	71.35	1.41

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX G

Table G1

Sentence stimuli used in Experiment 4.

Terminal words for the following sentences were manipulated in Experiment 4. All high probability words for the sentences are homophones. The level of cloze probability for each sentence is indicated in brackets.

1.	(.95)	The player ran to first base.
	(1.00)	Sam adjusted the sound of the stereo using the treble and the bass.
2.	(1.00)	The little girl has long brown hair.
	(.95)	The teacher told her class a story about a tortoise and a hare.
3.	(1.00)	That large brown animal is a grizzly bear.
	(.95)	Old Mother Hubbard's cupboards were bare.
4.	(.95)	Karen went on the ferris wheel at the country fair.
	(.90)	Cindy took out enough money for bus fare.
5.	(.95)	The article discussed the inequality between the rich and the poor.
	(.85)	The cement was mixed and ready to pour.
6.	(.95)	The patient was given medicine to ease her pain.
	(.80)	The children broke the neighbour's window pane.
7.	(1.00)	The worker climbed up the telephone pole.
	(.95)	Eight hundred people were surveyed in a Gallup poll.
8.	(1.00)	Billy put his tooth under his pillow for the tooth fairy.
	(.95)	Julie took her car over to PEI on the ferry.
9.	(.95)	The long math lecture was such a bore.
	(.75)	A wild pig is also called a boar.

APPENDIX G

Table G1 con't

10.	(1.00)	Tomorrow the ship will set sail.
	(.95)	The shop was having a closing-out sale.
11.	(.95)	Sally flew to her destination in a small plane.
	(1.00)	Yoghurt is sold either with fruit or it is just plain.
12.	(.95)	The dove is a sign of peace.
	(.95)	The class baked a cake and everyone had a piece.
13.	(.75)	Before fainting the woman's face became very pale.
	(.85)	Donna built a sandcastle with her shovel and pail.
14.	(1.00)	The man wanted the tickets so much he would beg, borrow or steal.
	(.95)	The cutlery is made from stainless steel.
15.	(1.00)	Of the six kittens half were female and half were male.
	(.90)	Each day the postman delivered Mary's mail.
16.	(1.00)	The dog wagged its tail.
	(1.00)	The campers listened to their leader tell an old wives' tale.
17.	(1.00)	The man ordered a T-bone steak.
	(.95)	Witches were burned at the stake.
18.	(.95)	The secretary went for her coffee break.
	(.80)	The cyclist stopped his bike using only the front brake.
19.	(.95)	Little boys are often dressed in the colour blue.

APPENDIX G

Table G1 con't

	(.90)	The tree broke when the strong wind blew.
20.	(.95)	When the princess kissed the frog it turned into a prince.
	(.95)	When Marie got her film developed she ordered a second set of prints.
21.	(1.00)	He gave his fiancee a long-stemmed rose.
	(.90)	In class the students sat in the first two rows.
22.	(.90)	The athlete threw the shotput the farthest it had ever been thrown.
	(.85)	The king sat down on the royal throne.
23.	(.70)	While going up to his bedroom Jim tripped on the top stair.
	(.70)	The woman's actions were so odd that people stopped to stare.
24.	(1.00)	Chocolate tastes very sweet.
	(1.00)	The newlyweds stayed in the honeymoon suite.
25.	(.75)	Tedious classes are often shorted than they seem.
	(.80)	When Gerald bent over his pants ripped along the seam.
26.	(.95)	The soldier's wounds took a long time to heal.
	(.75)	Tina's dress shoe has a broken heel.
27.	(.80)	The figures in the wax museum looked very real.
	(.55)	Jason bought a fishing rod and reel.
28.	(.76)	Frank buttered his dinner roll.
	(1.00)	The experienced actor was given the leading role.
29.	(1.00)	The dog whistle is too high for humans to hear.

APPENDIX G

Table G1 con't

	(1.00)	You can't get there from here.
30.	(.80)	To keep the boat from sinking Josh had to bail.
	(.60)	The farmer stacked the last hay bale.
31.	(.90)	Ray ran the obstacle course.
	(.70)	Table salt is fine grained but rock salt is coarse.
32.	(.93)	The grass was wet from the morning dew.
	(1.00)	Joan handed her essay in when it was due.
33.	(.95)	A butcher prepares many types of meat.
	(.95)	The couple decided on a time when they could meet.
34.	(.50)	A tasty purple vegetable is the sugar beet.
	(.70)	Rock music has a strong beat.
35.	(1.00)	The shoes were too small for Mike's feet.
	(.68)	Winning a gold medal is quite a feat.
36.	(1.00)	The church steeple has a weather vane.
	(1.00)	A lot of blood flows through the jugular vein.
37.	(1.00)	Belts are worn around your waist.
	(1.00)	The company was fined for dumping nuclear waste.
38.	(.95)	The congregation kneeled down to pray.
	(.95)	Hawks and eagles are birds of prey.
39.	(.80)	Many people refuse to wear animal fur.
	(1.00)	This type of tree is called a Douglas fir.

APPENDIX G

Table G1 con't

40.	(.93)	There are seven days in a week.
	(.73)	Doug is strong but Joe is really weak.
41.	(1.00)	The month of June has thirty days.
	(.60)	The bump on the head left Bill in a bit of a daze.
42.	(1.00)	Sharon tried on many shoes before she bought a pair.
	(.71)	Rob bought an apple, orange and a pear.

APPENDIX G

Table G2

Sentences that had non-homophonic terminal words as high probability words. The level of cloze probability for each sentence is indicated in brackets.

1.	(1.00)	There are sixty seconds in a minute.
2.	(.79)	The bank robber escaped with all the money.
3.	(1.00)	The old lady sat in her rocking chair.
4.	(.92)	The salad dressing was made with vinegar and oil.
5.	(1.00)	Jenny's mother told her a bedtime story.
6.	(.88)	Jenny served the dinner on a china plate.
7.	(1.00)	Mom baked the bread in the oven.
8.	(1.00)	The hockey player laced up his skate.
9.	(1.00)	Tim walked his dog on a leash.
10.	(1.00)	She swept the porch with a broom.
11.	(.79)	Mary raked the autumn leaves into a large pile.
12.	(1.00)	Terry hung the picture on the wall.
13.	(1.00)	Michelle stirred the sauce with a wooden spoon.
14.	(1.00)	The soccer players ran out onto the playing field.
15.	(1.00)	The police officer gave Jack a speeding ticket.
16.	(1.00)	The pot of gold is at the end of the rainbow.
17.	(1.00)	She unlocked the car with a key.
18.	(1.00)	Tommy brought a present to the birthday party.
19.	(1.00)	Mom made some chicken noodle soup.
20.	(1.00)	Janice knocked on her neighbour's front door.

APPENDIX G

Table G2 con't

21.	(.96)	Tony wants to go to the rock concert.
22.	(1.00)	George wants to open a bank account.
23.	(.96)	Marie went outside to mow the lawn.
24.	(.73)	At the conference we stayed in a hotel room.
25.	(.84)	The author's novel was made into a movie.
26.	(1.00)	The singer had a bad case of strep throat.
27.	(.88)	The campers cooked dinner over an open fire.
28.	(1.00)	The comedian's joke was really funny.
29.	(1.00)	The laundry soap did not remove the coffee stain.
30.	(1.00)	The hunters heard the lion's mighty roar.
31.	(1.00)	Donna bought bread at the corner store.
32.	(.96)	The sad film made the woman cry.
33.	(1.00)	Jason lost his driver's license.
34.	(1.00)	Laura's parents enrolled her in a private school.
35.	(1.00)	The artist mixed a new shade of red paint.
36.	(.86)	We made a great home-cooked meal.
37.	(.64)	Gina bought lunch for her friend.
38.	(.68)	At the recreation centre Gina learned how to dance.
39.	(.86)	The cowboy tied the calf's legs with a rope.

APPENDIX G

Table G2 con't

40.	(1.00)	Jessica got an apple from the fridge to eat.
41.	(1.00)	Michael borrowed a novel from the public library.
42.	(.63)	Peter is short but Bob is really tall.

APPENDIX G

Table G3

Pseudofoils and Orthographically similar words associated with homophone pairs used in Experiment 4

Homophone Pair	Pseudofoil	Proportion	OS-Word
base/bass	bace	(.87)	best
bear/bare	bair	(1.00)	burr
thrown/throne	throan	(1.00)	thread
fair/fare	fayr	(1.00)	fort
fairy/ferry	farie	(1.00)	flair
peace/piece	peece	(1.00)	peach
male/mail	mayl	(.87)	mint
tail/tale	tayl	(.87)	torn
steak/stake	staik	(.93)	sheet
break/brake	braik	(1.00)	brace
blue/blew	bloo	(.87)	bald
rose/rows	roze	(1.00)	race
roll/role	roal	(1.00)	ramp
hear/here	heer	(1.00)	hike
hair/hare	hayr	(1.00)	hold
pain/pane	payn	(.93)	port
sail/sale	sayl	(1.00)	sort
plane/plain	playn	(1.00)	place
pale/pail	payl	(.87)	pine
prince/prints	prinse	(1.00)	plants
stair/stare	stayr	(1.00)	sorry

APPENDIX G

Table G3 con't

bail/bale	bayl	(.93)	bull
poor/pour	poar	(1.00)	palm
pole/poll	poal	(1.00)	pike
course/coarse	corrse	(1.00)	crunch
dew/due	doo	(1.00)	dot
meat/meet	mete	(1.00)	mule
beet/beat	bete	(1.00)	bolt
feet/feat	fete	(.93)	fern
steel/steal	stiel	(.87)	sleet
sweet/suite	swiet	(.80)	swear
pair/pear	payr	(.87)	pill
heal/heel	hele	(.87)	hurt
real/reel	rele	(.93)	rest
vane/vein	vayn	(1.00)	vile
waist/waste	wayst	(1.00)	wrath
pray/prey	prai	(1.00)	pure
boar/bore	bowr	(.87)	brim
seam/seem	siem	(.80)	sick
fur/fir	fer	(.93)	fit
week/weak	wiek	(1.00)	wart
days/daze	daiz	(.93)	drop

APPENDIX G

Table G4

Pseudofoils and Orthographically similar words associated with non-homophonic words used in Experiment 4

Non-Homophone	Pseudofoil	Proportion	OS-Word
minute	minnit	(.93)	matter
money	munni	(1.00)	motel
chair	chare	(.87)	chant
oil	oyl	(.87)	ore
story	stori	(1.00)	stale
plate	plait	(.93)	pouch
oven	ovin	(.85)	oval
skate	skait	(1.00)	slime
leash	leesh	(1.00)	leaps
broom	brume	(1.00)	brain
pile	pyle	(1.00)	pawn
wall	waul	(1.00)	warn
spoon	spune	(.93)	shoot
field	feeld	(1.00)	fence
ticket	tikket	(1.00)	teller
rainbow	ranebow	(1.00)	rambles
key	kee	(.93)	kin
party	parti	(.80)	pride
soup	soop	(.80)	sunk
door	doar	(1.00)	doll
concert	consurt	(1.00)	chamber

APPENDIX G

Table G4 con't

account	akkount	(.95)	arrived
lawn	laun	(.80)	lack
room	rume	(1.00)	rail
movie	moovy	(1.00)	mouth
throat	throte	(1.00)	things
fire	fier	(.87)	fist
funny	funie	(.93)	flute
stain	stayn	(1.00)	start
roar	rore	(.93)	rind
store	stoar	(1.00)	share
cry	cri	(1.00)	cot
license	licents	(1.00)	lighten
school	skoole	(1.00)	shadow
paint	paynt	(1.00)	power
meal	meel	(.93)	mend
friend	frennd	(1.00)	flight
dance	dants	(.93)	desks
rope	roap	(.93)	ripe
eat	eet	(1.00)	eel
library	lybrari	(1.00)	letters
tall	tawl	(.93)	talk

APPENDIX H

Table H1

Standardized test results from Experiment 4.

	Raw (SD)	Scaled (SD)	Range
WRAT-3 Reading	49.65 (3.52)	106.35 (10.65)	44-56
WRAT-3 Spelling	45.71 (2.84)	109.82 (6.81)	42-52
PIAT-R Reading	93.94 (3.51)		86-98
PIAT-R Spelling	93.06 (4.04)		83-100
Woodcock-Johnson Word Attack Test	38.71 (3.90)		28-44
Auditory Analysis	36.59 (3.43)		25-40

Note: Scaled scores are presented only for the WRAT-3 reading and spelling tests. The scaled scores for the PIAT-R were not provided because subjects in the experiment exceeded the maximum age level.

APPENDIX I

Table I1

ANOVA for N400 Amplitude Data for Condition X Site Analysis for Experiment 4

Source	df	MSE	F
Condition	5, 85	79.96	13.69***
Site	14, 238	36.17	5.94*
Condition X Site	70, 1190	5.35	2.55*
Normalized	70, 1190	7.27	1.77

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX I

Table I2

Mean N400 amplitudes (in μV) (and Standard Deviations) for main effect for Condition factor for Experiment 4

Stimulus Condition	
CONGRUENT	2.94 (4.72)
FOIL	-0.88 (5.87)
PSEUDOFOIL-HOMOPHONE	-1.51 (5.21)
PSEUDOFOIL-NONHOMOPHONE	-1.23 (5.35)
OS-HOMOPHONE	-2.09 (3.99)
OS-NONHOMOPHONE	-3.08 (5.62)

APPENDIX I

Table I3

Mean N400 Amplitudes (in µV) (and Standard Deviations) for the main effect for Site factor for Experiment 4

Sites	
Fz	-1.02 (6.32)
F3	-1.46 (6.15)
F4	-0.93 (5.89)
F7	-2.31 (4.99)
F8	-1.23 (4.27)
Cz	-0.51 (6.40)
C3	-0.66 (5.28)
C4	0.60 (5.41)
Pz	-0.93 (6.41)
P3	-0.79 (5.73)
P4	1.38 (5.15)
T3	-1.62 (4.21)
T4	0.25 (3.73)
T5	-0.40 (4.95)
T6	2.96 (4.98)

APPENDIX I

Table I4

ANOVA for N400 Amplitude Data for Condition X Region X Hemisphere Analysis for Experiment 4

Source	df	MSE	F
Condition	5, 85	42.40	13.55***
Region	3, 51	38.31	4.75*
Hemisphere	1, 17	48.70	13.91*
Condition X Region	15, 255	6.68	2.77*
Normalized	15, 255	6.22	1.65
Condition X Hemisphere	5, 85	5.88	1.18
Region X Hemisphere	3, 51	6.63	6.10*
Condition X Region X Hemisphere	15, 255	1.03	3.38*
Normalized	15, 255	2.17	2.57*

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX I

Table I5

Mean Amplitudes (in μV) (and Standard Deviations) for the N400 component for the Condition X Region X Hemisphere Analysis for Experiment 4

	Left Hemisphere			
	Frontal	Central	Temporal	Parietal
Congruent	1.01 (3.93)	2.91 (3.79)	1.85 (2.93)	2.97 (3.71)
Foil	-2.73 (5.36)	-1.34 (4.40)	-1.05 (4.73)	-2.11 (5.22)
Pseudofoil-Homophone	-4.40 (5.48)	-2.48 (3.37)	-1.90 (5.20)	-0.25 (4.58)
Pseudofoil-Nonhomophone	-2.54 (6.22)	-1.88 (3.77)	-1.48 (5.34)	-1.01 (5.98)
OS-Homophone	-3.35 (4.08)	-1.89 (2.08	-2.83 (3.30)	-2.64 (3.47)
OS-Nonhomophone	-2.83 (6.20)	-2.97 (4.37)	-4.00 (5.63)	-4.90 (5.92)
	Right Hemisphere			
	Frontal	Central	Temporal	Parietal
Congruent	1.92 (4.07)	4.58 (4.08)	3.92 (3.03)	4.38 (3.70)
Foil	-1.54 (4.94)	2.11 (4.55)	-0.14 (5.75)	1.53 (6.98)
Pseudofoil-Homophone	-2.22 (5.00)	1.04 (3.14)	0.34 (4.64)	1.60 (4.12)
Pseudofoil-Nonhomophone	-2.02 (4.90)	0.72 (2.77)	-0.64 (5.05)	0.58 (4.58)
OS-Homophone	-2.70 (3.50)	0.62 (3.17)	-1.50 (3.52)	-0.25 (3.77)
OS-Nonhomophone	-3.18 (4.67)	-0.64 (3.05)	-3.38 (4.92)	-1.92 (1.16)

APPENDIX I

Table I6

ANOVA for N400 Latency Data for Condition X Site Analysis for Experiment 4

Source	df	MSE	F
Condition	5, 85	13844.71	2.17
Site	14, 238	199.53	2.77*
Condition X Site	70, 1190	117.90	0.94

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX I

Table I7

Mean N400 Latencies (in μσ) (and Standard Deviations) for the main effect for Site factor for Experiment 4

Sites	
Fz	396.30 (37.54)
F3	398.53 (41.45)
F4	396.01 (36.91)
F7	396.10 (36.92)
F8	396.07 (36.49)
Cz	396.08 (38.85)
C3	396.24 (38.55)
C4	395.46 (38.45)
Pz	393.87 (38.05)
P3	394.41 (38.91)
P4	395.82 (37.72)
T3	392.79 (37.04)
T4	395.18 (36.49)
T5	399.38 (42.02)
T6	400.78 (36.74)

APPENDIX I

Table I8

ANOVA for N400 Latency Data for Condition X Region X Hemisphere Analysis for Experiment 4

Source	df	MSE	F
Condition	5, 85	7332.12	2.19
Region	3, 51	132.13	5.05*
Hemisphere	1, 17	139.20	1.96
Condition X Region	15, 255	99.70	1.05
Condition X Hemisphere	5, 85	95.79	0.82
Region X Hemisphere	3, 51	73.55	0.30
Condition X Region X Hemisphere	15, 255	57.51	0.93

* $p < .05$; ** $p < .001$; *** $p < .0001$

APPENDIX I

Table I9

Mean N400 Latencies (in ms) (and Standard Deviations) for main effect for Region factor for Experiment 4

Region	
Frontal	396.68 (36.96)
Central	394.86 (38.44)
Temporal	397.03 (35.97)
Parietal	395.12 (38.26)

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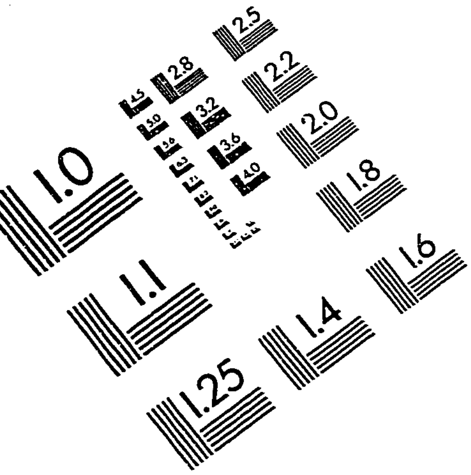
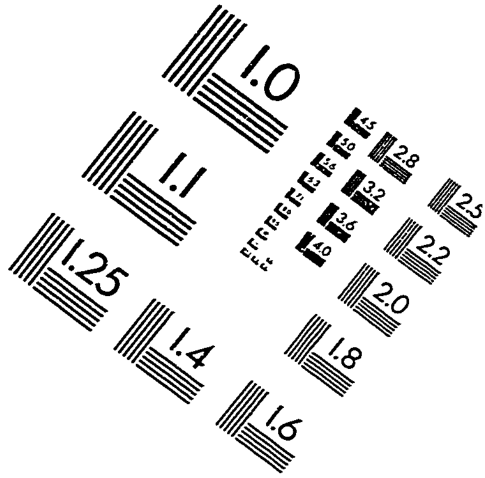
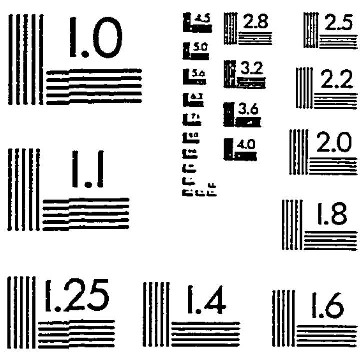
IMAGE EVALUATION TEST TARGET (QA-3)

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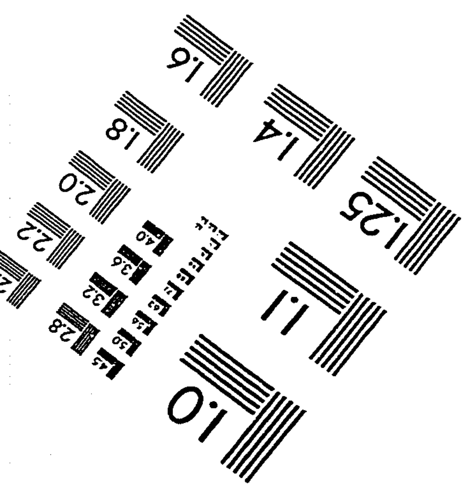
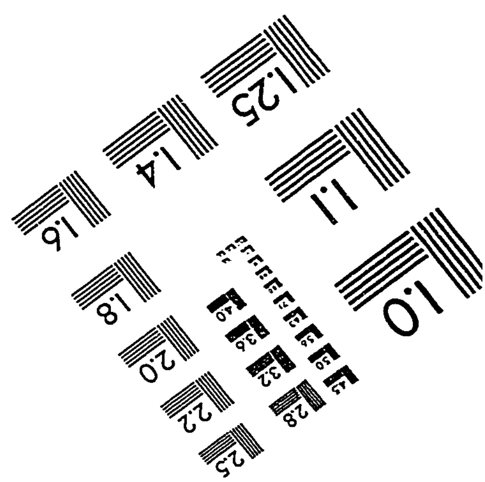

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