2002

Event-related potentials in word-pair processing

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Event-related Potentials in Word-pair Processing

A thesis submitted in fulfilment of the

requirements for the award of the degree

Doctor of Philosophy

from

UNIVERSITY OF WOLLONGONG

by

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Department of Psychology

2002

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ABSTRACT

Event-related potentials were used to investigate brain activity during language processing in word-pair paradigms. The issues addressed related particularly to the sensitivity of the N400 component to semantic processing, the automaticity of N400 processing and component overlap between the N400 and P3. A better understanding of N400 processing was obtained by considering the role played by other ERP components in the ERP signature. Component processing and identification were investigated using manipulations of experimental design and selected data analysis techniques (principal components analysis and difference waves). These techniques indicated differences in the magnitude of the N400 effect between tasks, demonstrating that the relatedness effect is task-dependent and therefore does reflect an automatic process. It was also shown that the N400 effect occurs independently of processing associated with the P3 component. The findings were interpreted in a variation of the Interactive Activation model proposed by McClelland (1989) to illustrate the flow of activation in each experimental condition.

CERTIFICATION

I, Joseph Graffi, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Department of Psychology, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Joseph Graffi

5th June 2002

ACKNOWLEDGEMENTS

I would firstly like to sincerely thank my supervisor, Professor Robert Barry, for his constant guidance, patience, commitment and support during this study.

I would also like to thank my family for providing me with the opportunity to pursue an education. I dedicate this work to my late father, Luigi.

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OVERVIEW

This thesis used the event-related potential to investigate brain activity during language processing in word-pair paradigms. The event-related potential is scalp-recorded electrical activity that is time-locked to a specific event. An averaging procedure is used to extract the event-related potential from the background electroencephalogram (EEG) because the scalp event-related potential is much lower in amplitude than the EEG in which it is embedded.

The event-related potential has proven to be a useful technique in the study of language because: it is a dependent measure that enables the monitoring of general mechanisms associated with word recognition, not merely task-specific factors; it enables the monitoring of specific processes across tasks; and it provides a good temporal account of sensory and cognitive processing in conjunction with scalp distribution.

The overlapping of components is one of the main complications arising from the use of the event-related potential. This occurs when multiple components are elicited in the same latency range, and the resulting measure reflects multiple processes that are often difficult to distinguish. This confound can be overcome through experimental design, carefully addressing the topography of the components and assessing the components in the context of the multiple processes which form the overall event-related potential.

The present experiments investigate semantic processing in relation to the N400 component. Specifically, they interpret the processing nature of the N400 and address the issue of component overlap between the N400 and P3 components. These issues were investigated by using a range of task manipulations, and selected data analysis techniques

(within-subject analysis of variance, principal components analysis and difference waves). The literature review covers information relating to language processing, with the range confined by the limits of the present research.

Semantic priming is the main process investigated in this thesis, and this is introduced in Chapter 1. That chapter discusses the main theories of semantic memory that have been proposed to account for semantic priming. The theories of semantic memory that assume the existence of a mental lexicon are discussed in relation to lexical and post-lexical processes. The type of activation associated with these processes is described as automatic and controlled, respectively. The validity of automatic and controlled processing as a conceptual dimension is also addressed. The literature regarding automatic and controlled processing indicated that the processing demands of the task influence the magnitude of the semantic-priming effect. When attention (controlled processing) is directed to the semantic attributes of the stimulus the semantic-priming effect is largest.

Chapter 2 briefly reviews how cognitive processing is conceptualised in terms of bottom-up or data-driven processing, and top-down or conceptually-driven processes, in relation to reading. The review deals with the assumptions regarding representation and activation. Representations tend to be either local or distributed, and processing is threshold or cascaded. These models were reviewed to provide a functional architecture in which the experimental finding could be interpreted.

Chapter 3 provides an anatomical perspective on reading. It outlines research from a variety of brain-imaging techniques and cortical-lesion studies in order to provide a

framework for cognitive functioning with respect to anatomical regions.

This thesis focuses on the N400 component of event-related potentials, so Chapter 4 outlines the factors known to influence this component, and discusses possible cognitive correlates. The literature associates the N400 with automatic lexical processing and also controlled post-lexical processing, with a tendency to favour the latter. Overall, the magnitude of the priming effect on N400 amplitude appears to be influenced by the extent of contextual processing.

The first of the experiments is presented in Chapter 5. The purpose of this study was to replicate the findings of Kutas and Hillyard (1989), who reported a priming effect on N400 amplitude using a letter-search task which was assumed to utilise non-semantic processing. This replication was undertaken because the findings reported seem contrary to the growing body of literature which suggests that the priming effect on N400 amplitude elicited by the target is enhanced in tasks that encourage semantic analysis. Principal components analysis (PCA) was used to identify the components, with processing assessed over the entire epoch, spanning both the first and second word presented, with a single pre-prime baseline. This provided a more-accurate account of overall processing than examination of the target ERP alone. This account was also enhanced by using stimulus position as a variable in the within-subjects repeated-measures analysis of variance.

Experiments 2 and 3 (Chapters 6 and 7) address processing differences using a within-subjects multi-task design. The aim was to use tasks which have been shown to implicitly generate an N400 effect without requiring an overt response (silent-reading and

memorisation) and compare them with a task in which subjects are explicitly aware of the semantic relationship between word-pairs and are using this information to make an overt button-press response (relatedness-judgement task). This design enabled the magnitude of the N400 effect between tasks to be assessed. It also assisted in addressing issues associated with component overlap. More generally, the event-related potential associated with each task was compared to assess processing differences between tasks. Again, PCA was used to identify components, and the epoch spanning both prime and target was used to perform the analysis.

Chapter 8 provides a summary of the components identified in each experiment using PCA, postulating the role these components play in overall processing of the word. The use of difference waves is then explored to assist in the assessment of the effects reported. The design techniques used in the current experiments to investigate processing and issues of component overlap are also discussed.

An attempt is made to model the flow of activation in each experimental condition in Chapter 9. The basic framework is based on the Interactive Activation model proposed by McClelland (1989). This modelling effort is a further attempt to address the overall processing reflected in the event-related potential. This is followed by Chapter 10, which provides an overall summary of the thesis and the key findings.

CHAPTER 1

SEMANTIC MEMORY AND PRIMING

Reading involves the generation of meaning from written text, and an understanding of this process would be facilitated by investigating how this generation uses the preceding text. This in turn involves the phenomenon of semantic priming. Semantic memory is a concept formed to account for how meaning is derived from the encoding, storing and retrieval of information. This introductory section will review elements of semantic memory theories proposed to account for semantic-priming effects, such as spreading activation, expectancy-induced priming, semantic matching/integration, plausibility checking, compound-cue and parallel-distributed processing. Processing within semantic memory will also be discussed, particularly in relation to automatic and controlled processes.

1.1. PRIMING

Processing words when reading text is assisted by the context that builds throughout the text. Even a single word (the prime) can provide sufficient contextual information to facilitate processing of a subsequent letter string (the target). This facilitation has been referred to as priming and has been quantified in terms of accuracy and reaction time for primed stimuli relative to unprimed stimuli. This thesis will focus on semantic-priming, a common priming paradigm in which a related prime precedes the target, for example, *bread-butter*. In this example, the prime and target are related through their use. This paradigm has produced consistent behavioural priming effects, reducing reaction time and increasing accuracy. Priming has been reported in different modalities and across

modalities, occurring with and without conscious effort, and emerging in a variety of tasks, such as word identification (Morton, 1969), sentence verification (Loftus, 1973), lexical decision (Becker, 1979; Meyer & Schvaneveldt, 1971; Neely, 1977), naming (Balota & Lorch, 1986; De Groot, 1985), and rhyme (Donnenweth-Nolan, Tanenhaus, & Seidenberg, 1981).

Lexical decision tasks are common vehicles in this research area, and require the subject to determine whether a visually-presented letter string forms a word or a non-word. The common finding is that subjects respond faster when the immediately-preceding word is semantically related than when it is unrelated.

1.2. ORGANISATION OF SEMANTIC MEMORY

Semantic-priming effects are thought to reflect how semantic memory is organised. The manner in which activation occurs in semantic memory will be briefly reviewed in relation to the basic mechanisms that are thought to underlie semantic priming. Theories of semantic memory usually describe activation in terms of 'automatic' and 'controlled' processes, which will be discussed extensively later. Automatic processes are described as spontaneous, of short duration, do not require attention or awareness, and are of unlimited capacity. It is stated that they cannot be controlled and do not interfere with other ongoing mental activity. In contrast, controlled processes are slow acting, require conscious attention, are of limited capacity, and enable the effect of expectancies and strategies (Logan, 1988; Posner & Snyder, as cited in Solso, 1975; Shiffrin & Schneider, 1977). Cognitive models of reading often refer to the mental lexicon or 'dictionary store' (Treisman, 1964). The mental lexicon consists of units of information referred to as lexical entries, which contain information about the pronunciation, meaning and spelling

of each word. The mechanisms thought to underlie semantic priming are lexical access and integration. Lexical access is described as an 'automatic' process that forms a representation of written or spoken words, and maps this representation onto the corresponding entries in the mental dictionary or lexicon. The process of lexical integration is described as 'controlled' and uses the lexical correlates of a spoken or written word to form a representation of the discourse based on the context (Brown & Hagoort, 1993). The common theories of semantic memory will be described in relation to the processes of lexical access and integration. The following section will selectively review theories of semantic memory proposed to account for semantic-priming effects. The different theories will be distinguished following the work of De Groot (1985) and Neely (as cited in Besner & Humphreys, 1991), and include the elements of spreading activation, expectancy-induced priming, semantic matching/integration, plausibility checking, compound-cue and parallel-distributed processing.

1.2.1. AUTOMATIC SPREADING OF ACTIVATION

Collins and Loftus (1975) assumed that each concept in semantic memory is represented by a node. Neely (1977) later referred to these as logogens. Nodes are linked to one another, if semantically or associatively related, to form a network. Retrieval of information from the network depends on an automatic process described as 'spreading activation'. The mechanism enabling processing to commence is 'activation' of a particular node. The level of activation at a node must exceed a threshold level to activate the decision and response systems. Activation of a node occurs spontaneously due to the spread of activation from other related nodes or via stimulation of the sensory system which provides symbolic representation of the concept. A node is said to be primed when a reduced level of activation is required to reach the recognition threshold. This reduction

is due to the automatic spreading of activation from other related nodes in the system. That is, the increase in activation has brought the node closer to the threshold level, reducing the level of activation required to reach the recognition threshold (Collins & Loftus, 1975; Neely, 1977; Posner & Snyder, as cited in Solso, 1975).

Neely (1977) assumed that word recognition and semantic priming are automatic processes. Presentation of a word was described as automatically activating its logogen. This activation spread to adjacent and semantically-related logogens, but not to semantically-unrelated logogens which are remotely distributed in the network. This was concluded from findings that showed semantic-context effects at short stimulus-onset asynchrony (SOA, the time from the onset of one stimulus to the next). This occurred even when list items were paired with exemplars from another category. The same conditions with a long SOA resulted in inhibition for related pairs. It was suggested that subjects had enough time at the long SOA to consciously use predictive strategies, whereas the short SOA did not allow enough time to engage such strategies, implying that word recognition reflected automatic processes.

1.2.2. EXPECTANCY-INDUCED PRIMING

According to Becker (1980, 1985) the presentation of a word without semantic context will result in the extraction of the visual features corresponding to its letters. These letters activate word nodes, which correspond visually to the word. The word nodes, which form a set, are referred to as the 'visually-defined set'. This set is searched in a serial manner, based on frequency. That is, high-frequency words are searched before low-frequency words. The search of the visually-defined set establishes whether the letters corresponding to the target word match those of the words in the visually-defined set. If a

target is preceded by a prime word, an expectancy set is generated based on the prime word. This expectancy set consists of words that are related to the prime. Upon presentation of the target, the visually-defined set is activated as described earlier. Occurring in parallel to this, a search proceeds in a serial manner to match a visual representation of the nodes in the expectancy set with the image of the target word in iconic memory. As opposed to the visually-defined set, which is searched sequentially in terms of word frequency, this matching process occurs serially in a random fashion. The model assumes that an exhaustive search of the expectancy set precedes the search through the visually-defined set, and it can therefore account for facilitory and inhibitory priming effects. In the case of associative priming, a small expectancy set can be generated based on those items that have a strong association with the prime. If the target forms part of this expectancy set it will be found quickly, resulting in facilitation. Inhibition will occur when the target is unrelated to the prime because the subject will perform an exhaustive search of the expectancy set and then will have to revert back to the visually-defined set to locate the unrelated target.

Posner and Snyder (as cited in Solso, 1975) proposed a model of semantic priming that incorporates the expectancy and automatic-spreading activation (ASA) mechanisms. As opposed to ASA, expectancy utilizes a limited-capacity attentional mechanism. Facilitation occurs for stimuli that activate nodes or that are the focus of attention. The limited-capacity attentional mechanism is assumed to be slow acting, requires conscious awareness and inhibits the retrieval of information stored in semantically-unrelated nodes which are not being focused upon. It had been suggested that the generation of an expectancy set takes time, and that such a mechanism can only account for effects which occur at intervals greater than approximately five hundred milliseconds (De Groot, 1984;

Neely, 1977), but Besner and Stoltz (1995) have shown that an expectancy set may be formed for related target words at SOAs as low as 200 milliseconds.

This mechanism utilises predictive strategy and can be influenced by manipulating task instruction and stimulus-list structure. For example, priming effects which are reinstated or occur using stimulus lists which contain a high proportion of related words demonstrate that the underlying mechanism is expectancy-induced priming (Chwilla, Brown, & Hagoort, 1995; den Heyer, Briand, & Dannenbring, 1983; Keefe & Neely, 1990; Stolz & Besner, 1996; Tweedy, Lapinski, & Schvaneveldt, 1977).

Automatic-spreading activation and expectancy priming provide an explanation of priming in terms of speeding-up access to the target's lexical node, and in this sense they can be considered to be prelexical models. Their difference lies in the assumption that ASA occurs automatically, whereas expectancy priming is a predictive strategy and assumes a limited attentional capacity which focuses on possible targets based on the prime and inhibits other information outside the focus of attention (Neely, as cited in Besner & Humphreys, 1991).

1.2.3. SEMANTIC MATCHING/INTEGRATION

Neely and Keefe (as sited in Bower, 1989) independently proposed the priming mechanism of semantic matching, which had been described previously by De Groot (1985) as the post-lexical integration mechanism. The models suggest that when the target has been presented and lexical access has occurred, the subject is able to use semantic information to determine whether the target semantically matches the preceding prime. This information can then be used to determine the lexical status of the target

word. For example, in a lexical-decision task, subjects are required to determine whether the target letter string forms a word or a non-word. This task will only generate a semantic match between the prime and target for word trials. Semantic matching provides a useful account of priming effects when the ratio of non-words is high, biasing a 'non-word' response (Neely, Keefe, & Ross, 1989). The study by Neely, Keefe and Ross (1989) varied the probability of non-words and the proportion of related words in two conditions, high- and low-dominance targets. They showed that increasing the probability of non-words increased priming in all conditions. However, when the relatedness proportion increased in conjunction with the probability increase of non-words, only priming for high-dominance target exemplars increased. It was concluded that varying the proportion of non-words affects semantic matching, whereas relatedness proportion influences expectancy.

The mechanism of semantic matching/integration is thought to be a controlled process associated with lexical integration. Such processes are described as slow acting, and require conscious attention which is of limited capacity (Neely, 1977; Posner & Snyder, as cited in Solso, 1975; Shiffrin & Schneider, 1977). Neely (as cited in Besner & Humphreys, 1991) suggested that the integration process is slow acting and therefore functions at relatively long interstimulus intervals (ISIs).

The two-process model of language comprehension proposed by Brown and Hagoort (1993) combined the mechanisms of automatic-spreading activation and integration. In this model processing begins with the automatic process of lexical access, that forms a representation of the physical signal, and maps this representation onto the corresponding entries in the mental lexicon. Activation of these entries spreads to a subset of associated

entries within the lexicon, along with their syntactic and semantic properties. The second process is lexical integration, described as a controlled process which engages the spoken or written word into a 'higher-order meaning representation of the entire discourse' (p.34). That is, the activated lexical item has syntactic and semantic specifications associated with it, which are matched with a representation in working memory containing the syntactic and semantic specifications of the current context. The efficiency of lexical integration depends on the match between these lexical and contextual specifications.

1.2.4. COMPOUND CUE

In the compound cue model proposed by Ratcliff and McKoon (1988), it is assumed that memory is comprised of a matrix specifying strengths between possible cues and concepts stored in the system. The mechanism by which an item's familiarity is assessed involves the summation of the strength between this cue and all images in memory. Decisions regarding recognition are then based on this familiarity value. The compound cue resulting from the prime and target is a positive function of their associative strength.

Priming is the result of greater familiarity of related prime-target compound cues compared to unrelated prime-target compound cues. The ability of the model to account for inhibition is quite limited. Inhibition in the unrelated condition is said to occur only when the neutral priming condition consists of a target which is related to that of the immediately-preceding trial. Therefore, reaction times will be facilitated in the neutral priming condition because the compound cue formed will consist of consecutive related words, whereas the unrelated condition will form compound cues always comprised of unrelated words. The inability of the theory to account for inhibition may arise from the way the compound cue is seen to be formed and then searched in memory. The

compound cue formed by the prime and target is a positive function of associative strength and the search in memory is one of familiarity, therefore it cannot produce inhibition *per se*.

Automatic spreading activation and semantic matching/integration have characteristics in common with the mechanisms of lexical access and integration, which are associated with ordinary language processing. Automatic spreading activation shares characteristics consistent with lexical access, whereas semantic matching/integration is associated with the post-lexical integration processes (Chwilla, Brown, & Hagoort, 1995; De Groot, 1984; Neely, as cited in Besner & Humphreys, 1991). The following chapter will describe models of language processing in order to provide a framework in which the function of these mechanisms may be explored.

1.2.5. DISTRIBUTED NETWORK

Hinton, McClelland and Rumelhart (as cited in Rumelhart, McClelland, and the PDP Research Group, 1986) proposed a model of memory in which the processing of episodic and semantic knowledge occurred in a parallel distributed-processing (PDP) framework. Episodic knowledge involves the temporal relationship between events, whereas semantic knowledge is constant and involves a person's organised knowledge of the world without temporal information. This network model of memory consists of interconnecting units whose connections are weighted. However, concepts are represented by a 'pattern of activation' over the entire network, as opposed to each unit representing a single concept in the node account. The extent to which activation of a unit influences that of another unit is determined by the connection weights. The weights also determine whether activation is excitatory or inhibitory. The weights are organised so that units occurring

together in several activation patterns will activate each other, whereas units which infrequently occur together will inhibit each other. The memory system is assumed to be composed of bundles of these units called modules. A set of interconnected modules can be organised into pathways. Pathways overlap if they contain modules in common. Priming can be conceptualised in this framework as activation overlap. That is, sematic priming is the overlapping semantic activation of features and context shared by prime and target.

1.3. AUTOMATIC AND CONTROLLED PROCESSING

There has been much debate regarding the processing properties of particular mechanisms relating to attention. An early account by Kahneman (1973) proposed a limited-capacity model of attention, in which capacity can be used at different stages of processing. He suggested that the processing demands of mental operations differ in terms of the attentional capacity required. The capacity demands of mental operations are described as a continuum - attention is not required to perform early levels of processing, such as sensory analysis, but attentional demands increase as processing proceeds toward the output stage. However, research has shown that practice of stimulus-response operations reduces the attentional capacity required to perform the task. Processing is described as becoming 'automatic', whereas processing that requires limited-capacity attentional resources is described as 'conscious' or 'controlled' (Neely, 1977; Posner & Snyder, as cited in Solso, 1975; Shiffrin & Schneider, 1977). Most of the current debate centers on the extent to which processing mechanisms utilize the limited capacity attentional resource(s).

Automatic processing is considered to be fast, inflexible, and parallel, which does not

require conscious attention or the depletion of the attentional resource(s). Controlled processing is considered to be slow, flexible, and serial, which requires conscious attention and draws upon the limited attentional resource(s) (Neely, 1977; Posner & Snyder, as cited in Solso, 1975; Shiffrin & Schneider, 1977).

Research has investigated automatic and controlled processing in terms of whether the target and distractor sets were variably mapped (VM) or consistently mapped (CM). Mapping refers to the formation of the relationship of both target and distractor stimuli to the response required. These experiments all involved some form of search task which used a memory set. The memory set consisted of the items to be detected and were learnt or previously presented. The VM condition consisted of a search task in which the mapping between the stimulus and response varied across trials, as opposed to the CM condition in which the mapping between the stimulus and response remained constant. The concepts above are illustrated as follows: There are two main variables, the *visual display* (the number of items in the display) and *memory set* (the number of targets that are required to be searched for). In this example the target memory set is N, J, L, and E, each visual display will contain four letters, and the task is to determine if any of those four letters is one of the four target letters in the memory set. VM means that the target set and the distractors change constantly over trials in such a way that a target in one trial can act as a distractor in another trial. CM trials are those in which the set of targets and distractors remains consistent, that is, the set of letters that are targets are always different from the set of letters acting as the distractors. In the CM condition it was shown that search time and accuracy improved substantially with practice, while increased task load did not alter performance. The lack of sensitivity to increased load was described as reflecting automaticity acquired through practice. This interpretation was supported in a

further manipulation, which showed that target search performance was initially inferior when stimulus-response mapping was reversed after practice in the CM condition. This reflected the inability of subjects to overcome the automaticity established through practice. This indicated that, once established, automatic processing was resistant to change.

According to Shiffrin and Schneider (1977), controlled processing functions in the limited capacity short-term store. In the short-term store, temporary activation of a set of nodes associated with an unlearnt sequence requires active attention. The VM condition was described as a serial, self-terminating comparison process in which the memory set item was compared to all the display items and a new memory set was formed across trials. In the VM condition it was shown that search time and accuracy did not improve with practice, indicating that practice alone does not necessarily produce an automatic process. Also, increased task load reduced performance, and the sensitivity to increased load was described as reflecting a limited capacity, serial comparison process. It was shown that this type of controlled search does not become automated with practice.

Schneider and Shiffrin (1977; Shiffrin & Schneider, 1977) concluded that automatic processing is the result of learning through the prior use of controlled processing. Such learning is said to establish activation networks in long-term store, which are not easily modified once learnt. When well-established inputs trigger the network, attention is attracted by initiating an 'automatic attention response', enabling recognition to be achieved independent of other processing demands. Similarly, Posner and Snyder (as cited in Solso, 1975) proposed a two-process theory of attention in which an automatic spreading activation process retrieves information from long-term memory.

Hasher and Zachs (1979) provided an alternate perspective to the all-or-none theories described above. They proposed a framework in which a continuum of attentional requirements is associated with encoding processes. Automatic and controlled processing form the extreme ends of the continuum. When attention is intentionally or incidentally focused on the input, some aspects of encoding are automatically entered into long-term memory (LTM). These include spatial location, time, frequency of occurrence, and word meaning. Automatic processing is said to be the result of heredity and practice. They suggested that humans are 'genetically prepared' with some automatic processes, such as processes that encode frequency, spatial location and time. This type of automatic processing is situated at the extreme end of the attentional continuum. Automatic processes acquired through practice, such as meaning extraction and reading, are considered to function differently from automatic processes that are innate, being subject to disruption and individual differences. Overall, learned automatic processing is considered to share some but not all of the features associated with innate automatic processing.

Shiffrin and Schneider (1977) had assumed that automatic processing activates nodes in LTM but cannot modify it directly, and that such processing emerges due to extensive practice. Hasher and Zacks (1979) suggested that such assumptions only apply to learned automatic processes and do not characterize innate automatic processes.

Hasher and Zacks (1979) proposed that an automatic process occurs optimally without intention and requires minimal attention, while controlled processing was defined as an 'effortful memory process'. Zacks, Hasher, and Sanft (1982) used a forced-choice frequency-discrimination task and reported that automatic processing was not sensitive to

task load, practice, individual differences, or the accuracy of test expectations. However, the use of a counting strategy facilitated processing. They acknowledged that the latter finding is at odds with the hypothesis, but avoided its implications and concluded that frequency is encoded by an automatic process. Controlled processing was investigated using a free-recall task because performance had been shown to be sensitive to such processing. They found that free-recall performance was sensitive to task load, practice, the appropriateness of the practice, individual differences, and the accuracy of test expectations. They concluded that free recall required effortful encoding processes that occurred optimally with intention and required attention.

Hasher and Zacks (1979) described controlled processing as an intentional, serial process, which becomes more efficient with practice and shows individual differences. The types of processing which are considered to be at the effortful end of the attention continuum include imagery, elaborative mnemonic processes, and rehearsal. The purpose of effortful processing is to make the acquisition of information more efficient. The processing is described as flexible, enabling it to cope with novel information. They suggested that, with sufficient practice, it is possible for such processing to become automatic. This description of controlled processing supports that of Shiffrin and Schneider (1977) except that, in this framework, there is no dichotomy between automatic and controlled processing. Attention is considered to be non-specific and of limited capacity, with the use of attention varying with the type of mental operation.

Fisk and Schneider (1984) investigated the link between processing and memory modification, specifically addressing the issue of frequency encoding and processing orientation. Recognition memory was used as an indicator of long-term memory

modification. Subjects were required to perform recognition-memory and frequency-estimation tasks subsequent to conditions manipulating processing orientation. These conditions consisted of intentional learning, in which subjects were told about a subsequent frequency-estimation task and had to perform semantic, graphic, and letter-search tasks. They also performed a digit-detection task in the presence of words, and were required to remember the words in one condition and ignore them in another. Intentional learning and semantic orientation resulted in the best performance, followed by graphic orientation and then the digit-detection task. That is, recognition memory and frequency estimation performance improved as controlled-processing demands increased across conditions. It was concluded that long-term memory storage was a function of the type and extent of controlled processing. The influence of encoding strategies on frequency-estimation performance implies that frequency is not encoded by an automatic process, but occurs optimally with intention and attention. This is in direct contrast to Hasher and Zacks (1979), who proposed that frequency is encoded by an automatic process, occurs optimally without intention, and requires minimal attention.

In a second experiment, Fisk and Schneider (1984) used a dual-task paradigm to determine whether automatic processing resulted in long-term memory storage. A variably-mapped digit search was used as the primary task in order to use limited attentional capacity. Word categorization formed the distractor task, in which subjects were trained extensively to establish automatic processing. Subjects also performed subsequent recognition-memory and frequency-estimation tasks. They found that recognition-memory and frequency-estimation performance was poor for previously-categorized words. It was concluded that automatic processing results in little or no long-term memory storage. This contradicts Hasher and Zacks's claim that when attention is

focused on the input, some aspects of encoding, such as frequency, are automatically entered into long-term memory. Fisk and Schneider (1984) showed that there is a close link between long-term memory modification and controlled processing, and that automatic processing can occur with minimal or no long-term memory storage. They also established that task-appropriate controlled processing resulted in better recognition-memory performance.

The Stroop (1935) task and its many variations have been a popular means of establishing the unavoidable nature of automatic processing (Anderson, 1995; Greenwald, 1972; Rayner & Pollatsek, 1978, 1989; Shaffer & LaBerge 1979). In the original task, subjects were required to name the ink colour of a printed word. It is well established that performance is faster when subjects name the ink colour of a congruent word than that of an incongruent word, e.g., red letters spelling the word 'red' as opposed to red letters spelling the word 'blue'. Subjects seem unable to selectively attend to colour information. This is said to indicate that reading is an automatic process in which semantic activation cannot be prevented (Anderson, 1995; Ashcraft, 1994; Rayner & Pollatsek, 1989; Reisberg, 1997).

However, Besner, Stolz, and Boutilier (1997) showed that the extent of semantic activation was task dependent. They directly tested the notion that semantic activation occurred automatically in the Stroop task. In their experiment either a single letter or the entire word was coloured, and subjects were required to identify the colour of the letter or word by making a keyboard response. The rationale was that, if the word was automatically processed to the semantic level, the magnitude of the Stroop effect should be the same in both conditions. However, they showed that the Stroop effect was

significantly reduced when a single letter, as opposed to the whole word, was coloured.

In a second experiment, congruent trials, ones in which the colour of the word or letter was the same as the word to be identified, were substituted by a neutral baseline condition comprised of nonwords. All other aspects of the experiment remained the same as the previous experiment. The rationale was that the Stroop effect is sensitive to congruent trials because it encourages subjects to read the irrelevant word. Therefore, replacing these trials with a neutral baseline should eliminate semantic-level processing of the irrelevant word. The results confirmed this, as the Stroop effect occurred when the whole word was coloured, but was now eliminated when a single letter was coloured. The elimination of the Stroop effect for single coloured letters in the second experiment showed that semantic-level processing was reduced even further than in the first experiment.

Their results are inconsistent with the widely-held notion that the Stroop effect is the result of subjects automatically processing the irrelevant word to the semantic level. They suggested that their findings were due to the task explicitly resulting in the word being processed in terms of letter form and colour, which is associated with lexical and letter-level activation. Instead of this activation flowing through to the semantic level, lexical-level information is fed back to enhance processing at the letter level. This implied that the word-recognition system has limited capacity, otherwise there would be nothing to prevent the flow of activation to the semantic level.

Earlier studies had also questioned the assumption that reading in the Stroop task is automatic. Kahneman and Henik (as cited in Dornic, 1976) used a Stroop naming task in

which a circle and a square were presented beside each other, but still in the central fixation area. Subjects were cued to the circle and were required to identify the colour of the word that appeared in the circle. They replicated the standard Stroop effect, showing that interference was greater when the word was irrelevant. However, they also showed that the interference was significantly reduced when the irrelevant colour word was presented in the adjacent square rather than the same location as the target colour. That is, the extent of interference was determined by whether attention was directed toward or away from the incongruent item. Attention was utilized to perform the task because if it were purely due to automatic processing the location should not have changed the extent of interference.

Francolini and Egeth (1980) found similar results in a task investigating whether distractor items are processed to recognition level. Red and black items were presented in a circular display and subjects were required to count only the red items. The results showed that counting two red As among black 3s produced no interference even though the distractor item was given 'Stroop qualities' in that the black symbols were inconsistent with the correct response relating to the number of red items. They also showed that counting two red 3s among black As produced a Stroop interference effect. In this case the relevant red item is described as automatically activating its associated meaning. It was concluded that automatic activation of an item is restricted to relevant information, in this case based on colour. Since activation is based on relevance it cannot be described as automatic *per se*, contradicting automatic activation theories described earlier which suggested that well-learned stimuli are processed independently of the attentional focus (Posner & Snyder, as cited in Solso, 1975; Shiffrin & Schneider, 1977).

The semantic-priming effect, in which a semantically-related context facilitates word recognition, is a robust and well-documented phenomenon. However, research has shown that the magnitude of the semantic-priming effect is influenced by the manner in which the prime is processed (Besner, Smith, & MacLeod, 1990; Friedrich, Henik, & Tzelgov, 1991; Smith, 1979). Semantic-priming effects were eliminated when the area surrounding the prime was searched for a visual probe (Smith, Theodor, & Franklin, 1983), when the prime was searched for a letter (Henik, Friedrich, & Kellog, 1983; Henik, Friedrich, Tzelgov, & Tramer, 1994), in counting tasks where the number of syllables or letters in the prime word had to be determined, and when the letter case of the prime word had to be established (Kaye & Brown, 1985). These results challenge the notion of automaticity. Facilitation does not necessarily occur when a target is preceded by a related prime; rather, the manner in which the prime is processed appears to determine whether facilitation occurs.

Smith (1979) performed an experiment manipulating the type of discrimination performed on both the prime and target, in which a single letter probe was positioned above each letter of target words - for example, if *bread* was the target word and the letter probe was *r*, then *r* would appear above each letter of the word *bread.* Target words were preceded by either an identical, related or unrelated word. The first task was to indicate whether the letter was present in the target word. The results indicated that the target word was searched faster when preceded by a related or identical prime relative to the unrelated prime. This implies that contextual priming had occurred. In a second task, subjects were required to search for a probe letter above both the prime and target. In this task, facilitation failed to occur. This suggested that the manner in which the prime was processed determined whether facilitation occurred. This has been supported by others

who have shown that when subjects were required to search the prime for a letter, a related prime failed to produce significant target facilitation (Henik, Friedrich, & Kellogg, 1983; Smith, Theodor, & Franklin, 1983).

Friedrich, Henik, and Tzelgov (1991) established that identity- and semantic-priming may occur in a naming task. An identity-priming task is one in which the prime is repeated as the target. However, when a letter search task (LST) was performed on the prime in the semantic- and identity-priming conditions, only the identity-priming condition showed priming effects. It was concluded that the LST affects the activation of semantic associates but enables lexical access of the prime, because it had been established that the priming effects in the identity-priming condition were not the result of letter-by-letter priming, and therefore not due to non-lexical priming processes. They proposed that this lack of priming, due to the disruption in activation of semantic features or associates of the prime word, could be the result of active suppression of semantic processing or a general failure to activate semantic associates. The active suppression of semantic processing suggests that spreading of activation may be disrupted because the analysis is taking place at a non-lexical level and may be actively suppressing other levels of analysis, such as the activation of semantic information. That is, activation of semantic associates is actively suppressed due to attention being focused at the letter level of analysis. A general failure to activate semantic associates implies that even early automatic-spreading activation requires some degree of attention, that is, the lack of priming may be the result of the letter-search task directing attention to non-lexical processes.

These two accounts were tested in a further experiment using a cross-modal priming

condition. This condition tried to determine whether performing a letter search on the prime would also interrupt spreading activation in the auditory modality. They found that priming was reinstated when an auditory prime preceded the visual prime. Therefore, they suggested that the active suppression account can be ruled out because it implied that even if spreading activation did occur, active suppression of the semantic features or associates of the prime word should have resulted when performing a letter-level analysis. The activation does not appear to be disrupted by a letter-search task as long as semantic activation is somehow initiated. It was concluded that the lack of priming in the letter-search task when only the visual prime is presented was possibly due to semantic activation either not occurring or decaying too rapidly to be effective. However, this assumes that suppression occurs in the same manner for orthographic and phonological encoding. It also assumes that activation of auditory and visual primes is achieved using the same process.

Henik, Tzelgov, Osimani and Friedrich (1991) used a dual-task paradigm in which subjects responded to either visual or auditory probes presented at the same time as the prime word. The visual probe consisted of an asterisk placed near the prime, and the auditory probe was a tone. The task also involved making a lexical decision to the target prior to the probe-detection response. The time interval from prime onset to target onset (SOA) was manipulated to try to determine if semantic-priming would be reduced at a short SOA (240 msec) relative to a long SOA (840 msec). The rationale for the use of SOA was that short SOAs would not allow attention to influence semantic-priming effects, relative to long SOAs in which attention effects have been found. It was reported that when subjects were required to search for a probe, priming was reduced or eliminated at both SOAs and in both modalities, relative to when no probe search was required. It

was concluded that even at time intervals which are thought to reflect rapid automatic processing, the priming effect is determined by the manner in which the prime word is processed.

Henik, Friedrich, Tzelgov and Tamer (1994) investigated relatedness proportion and the effects of SOA on semantic priming when the prime was either named or searched for a specific letter. At a relatedness proportion (proportion of related word pairs in the stimulus list) of 50 %, priming effects were found at SOAs of both 240 msec and 840 msec for the naming task, but no priming occurred at either SOA when the prime was searched for a letter. In a further experiment, both the relatedness proportion and SOA were varied. When the relatedness proportion was 20 %, no priming effects occurred in the letter-search condition at either SOA. However, priming did occur at both SOAs when the relatedness proportion was increased to 80 %.

These findings support the notion that priming effects depend on how the prime is processed. As in the research by Henik, Tzelgov, Osimani and Friedrich (1991), SOAs thought to reflect the fast automatic spreading activation process appear to require attention at the semantic level if priming effects are to occur. However, the letter-search task required attention at the non-lexical level, and priming was restored at both SOAs when the relatedness proportion, and hence attention at the semantic level, was increased. The researchers suggested that the short SOA may not allow enough time to alter attentional focus, but that the task demands themselves may determine the level of analysis required. In the case of the letter-search task, subjects may allocate whatever resources are necessary prior to presentation of the prime. They suggested that elimination of priming effects, when relatedness proportions were varied, could have

reflected the lack of processing at the semantic level due to a letter search of the prime word. That is, lexical access occurs for the prime under letter search conditions, but activation does not appear to spread to related concepts.

1.4. SUMMARY

This chapter introduced the phenomena associated with semantic priming, the main process investigated in this thesis. How semantic priming is thought to function was discussed in relation to theories of semantic memory, which use the mechanisms of lexical access and integration to account for semantic priming. These processes are described as automatic and controlled, respectively. The key conclusion from reviewing the literature on automatic and controlled processing was that the magnitude of the semantic priming effect depends on the processing demands of the task. The semantic-priming effect is largest when the task requires attention (controlled processing) to semantic attributes, in particular to those of the prime. Automaticity is defined as a process that does not require conscious attention. However, if attention is considered to be a continuum, then the concept of automaticity becomes redundant unless automatic and controlled processes represent either end of the continuum, in which case it takes on a slightly different definition.

Theories of semantic priming attempt to describe how processing occurs at the semantic level. The following chapter will review general models of language processing, placing the cognitive operations at the semantic level in context with other processes.

CHAPTER 2

COGNITIVE PROCESSING MODELS OF LANGUAGE

Over the years, cognitive models of language have moved from a simplistic descriptive approach, using boxes and arrows, to a computational approach. Most models consist of distinct cognitive modules, and it has been proposed that processing in these modules can be thresholded or cascaded, and representations can either be local or distributed. Threshold processing is serial - activation flows from one module to the next when a threshold is achieved in the earlier module. Cascaded processing does not work on a threshold principle - once any degree of activation occurs in a module it flows through to later modules. The localist perspective suggests that each concept is represented as a node, and that semantic-priming is the result of a node coming closer to its threshold level due to preactivation. The distributed account suggests that concepts are represented as a pattern of activation across nodes, and the context shared by prime and target results in semantic priming when the prime and target activate semantic features that overlap. These aspects will be discussed briefly to provide a general account of how information is thought to flow and interact in the reading process.

2.1. MODULAR PROCESSING MODEL

The architecture of early language-processing systems was modular and adopted the box and arrow notation (Lichtheim, 1885; Treisman, 1964). An example of a distinct cognitive module is the mental lexicon or 'dictionary store' proposed by Treisman (1964). The term 'dictionary units' is used to refer to sublexical systems of information which form the lexicon. In Treisman's model, these dictionary units, or lexical entries, contain

information about the pronunciation, meaning and spelling of each word. To obtain meaning when reading a word, information from the word must be extracted to enable access to the word's lexical entry. Such lexical access is necessary given that semantic information is stored as part of the word's lexical entry. This implies that the processing underlying reading and speech perception involves distinct stages. That is, visual characteristics of words need to be extracted in order to access the semantic information stored as part of the lexical entry. Treisman (1964) also proposed that lexical entries form an associative network connecting semantically-related words. Once the lexical entry for a word is accessed it will enable temporarily-increased accessibility to semantically-related words. As a result of this, the threshold level of semantically-related words is reduced. Morton (1961) proposed two distinct mental lexicons called the 'cognitive system', involving knowledge about word meanings, and the 'logogen system' (or word generation system), involving knowledge about word forms. Logogens are evidence-gathering devices with thresholds. The visual or auditory input gathers evidence, and the meaning of the word is accessed in the cognitive system when the evidence collected by a word's logogen exceeds its threshold. The later versions of the model (Morton, as cited in Kolers, Wrolstad, & Bouma, 1979, as cited in Mehler, Walker, & Garrett, 1982) were far more complex and its development was motivated by empirical results. Processing in these models is serial, due to the nature of logogen processing, as one module must reach its threshold before activation of the next module can occur.

2.2. BOTTOM-UP PROCESSING MODEL

Processing described in terms of serial, hierarchical and modular models provide 'bottom-up' or data-driven accounts of reading. They emphasize a serial, part-to-whole processing of text, in which meaning is derived from the elements of the text. The early stages of

processing in these models are not influenced by pragmatic or contextual information (Dechant, 1991; Forster, as cited in Cooper & Walker 1979). Such models are based on the principle that text is hierarchically organized in terms of graphonics (the sound relationship between the orthography and phonology of a language), phonetics, syllables, morphemics (identifying words by analysing the meaning parts of the words), word and sentence levels. Processing initially begins with the smallest linguistic units or modules, enabling the accumulation of information necessary to decipher and understand higher units. This implies that each unit or module is only affected by the processing immediately preceding it, in a hierarchical manner, with each module being influenced only by the outcome of lower-level operations (Dechant, 1991; Fodor, 1983, 1985; Forster, as cited in Cooper & Walker, 1979; Gough, Alford, & Holley-Wilcox, as cited in Tzeng & Singer, 1981).

The bottom-up approach has found support from experiments establishing that a word's meaning can be initially accessed independently of the semantic context in which it is presented. For example, Conrad (1974) used a colour-naming paradigm and found that the appropriate meaning for a word which had two distinct meanings occurred at the time the word was heard in the sentence. Contextual constraints favouring a single meaning failed to prevent both meanings from being activated. Moss and Marlen-Wilson (1993) performed a similar study, and also concluded that word meaning is activated independently of its context. Conrad (1974) suggests that a word's meaning is activated in a serial manner and subsequent post-lexical processing resolves ambiguities using appropriate contextual information.

2.3. TOP-DOWN PROCESSING MODEL

In contrast to the bottom-up model, 'top-down' or meaning-driven processes postulate the reader forming assumptions regarding the meaning of the text, and identifying letters and words to confirm these assumptions (Goodman, as cited in Singer & Ruddell, 1970; Dechant, 1991; Smith, 1994). Smith (1994) suggested that decoding skill, that is, being able to analyse and interpret correctly-spoken or graphic symbols of a familiar language, is based on comprehension. Comprehension enables meaning to be brought to the text, not derived from it.

Goodman (1981) suggested that the aim of reading is to construct meaning in response to text. His reading model assumed that the reader generates hypotheses about upcoming information, based on their world knowledge and the contextual information. He considered meaning to be derived from the interaction of different cues that help to decode and comprehend text. The cues described included graphaphonic cues (hints based on the sound relationship between orthography and phonology), syntactic or grammatical cues (the way words are combined to form phrases, clauses or sentences), and semantic cues (hints based on meaning). In this model the text forms the input, and meaning the output. The reader also provides input, interacting with the text efficiently by using as few cues as possible from the text to construct meaning.

Rayner and Pollatsek (1989) pointed out several weaknesses in Goodman's model, particularly its vagueness. For example, Goodman suggested that contextual information guides the selection of visual features, and that cues are used to facilitate word recognition, but did not specify how this occurs.

The bottom-up and top-down approaches to understanding the cognitive processing involved in reading text can be summarized as follows. The former emphasizes written or printed text: reading is driven by processing text and forming meaning, and is therefore often described as proceeding from part to whole. The latter approach emphasizes what the reader brings to the text: reading is driven by meaning and is therefore described as proceeding from whole to part.

2.4. PARALLEL, DISTRIBUTED AND INTERACTIVE MODELS

Parallel, distributed and interactive models are more complex, and attempt to combine the concepts of bottom-up and top-down processes, acknowledging the simultaneous interaction of these processes throughout the reading activity. Meaning is constructed from multiple sources, including graphemic (letter or letters representing one phoneme), phonemic (set of the smallest units of speech used to distinguish one utterance from another), morphemic (identifying words by an analysis of the meaningful parts of those words), syntax and semantics, without being restricted to any one set or order. These models suggest that the reader uses all levels of processing, with the most relevant sources of information receiving greatest activation (Balota, as cited in Balota, Flares d'Arcais, & Rayner, 1990; Dechant, 1991; Goodman, 1981; McClelland, 1987; Massaro, 1979; Rumelhart, as cited in Singer & Ruddell, 1985).

The word-superiority effect has provided support for top-down interactive processing in reading. The effect is obtained when an isolated letter like *K*, or a word like *WORK*, is briefly flashed on the screen and then replaced with a mask of Xs and Os. The task is to determine whether a D or a K was presented. It was reported that detection was better when the letter formed part of a word than when it was presented in isolation, and this was

labelled the word-superiority effect (Reicher, 1969; Wheeler, 1970). This effect poses a problem for bottom-up modular models because information cannot flow from the word level to the letter level. McClelland and Rumelhart (1981) accounted for this effect by incorporating top-down processing from the word level to the letter level. Other important empirical evidence supporting top-down interactive processing is the sentence superiority effect for words - words are perceived with greater accuracy when they form part of a sentence than when they are presented in scrambled text - and also the sentence inferiority effect for letters - letters are less accurately perceived when in words that form part of sentences (Masson & May, 1985). Also, Healy and Drewnowski (1983) reported that letter detection when reading text was enhanced when the letter formed part of a nonword, than when it formed part of a word. This suggests that sentence processing may automatically bias attention to higher levels of processing, involving the word and meaning levels, but degrade processing at the lower letter level.

Interactive modelling has moved towards a computational approach rather than representing theories as descriptive verbal models. This thesis is not concerned with the computational nature of the model, but certain aspects of such models will be described in order to provide a background to the functional architecture in these models. There are two main approaches to computational modelling. The first uses a learning algorithm involving back propagation. It is a three-layered network consisting of input units, hidden units, and output units, with the weights set initially at small random values (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). An extensive training period occurs in which stimulus-response pairs are processed through the model. The training results in the learning algorithm progressively adjusting the weights between the connections in the network, so that for each stimulus represented by the input units, the

response represented across output units more closely corresponds with the actual response. A criticism of this method is that the architecture of the model is constrained by the algorithm. That is, the learning algorithm trains the network to be able to perform the task, without specific functional architecture. The lack of functional architecture makes it difficult to determine how the algorithm has trained the network to perform the task. This is overcome in the second approach to computational modelling, in which the modeller specifies the functional architecture of the model and then uses the learning algorithm to adjust the strengths of the connections between prespecified modules of the model (Coltheart, Curtis, Atkins, & Haller, 1993).

The following section will focus on functional architecture of these modular interactive models of language processing at the single word level. The boxes in the following diagrams represent the modules and the arrows from one module to another depict the flow of information between modules.

2.5. INTERACTIVE ACTIVATION AND COMPETITION (IAC)

The IAC model represents an early computational model of visual word recognition. The functional architecture of the model was specified by its creators to consist of three representational levels, the visual feature level, letter level, and orthographic word level (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). McClelland (1979) suggested that serially-organised discrete processing modules, which require that processing at one module reach its threshold before activation of the next module can occur, are an oversimplification of how processing occurs. In contrast to the concept of threshold, McClelland (1979) proposed the cascaded processing system, with no thresholds within modules. Any activation in early modules flows through to later

modules in a progressive manner. The model maintains the notion that the components of processing are localised. McClelland (as cited in Coltheart, 1987) expanded the visual word recognition model but explication of the model here will be restricted to three levels, the letter level, word level, and semantic level, as represented by Stolz and Besner (1996) (see Figure 2.1). In this model, McClelland changed from his earlier views, favouring the distributed components of processing account, in which concepts are represented by a unique pattern of activation over the entire network of nodes. He specified that both within- and between-level activation is bi-directional. The connections between levels are represented by the arrows in Figure 2.1, and activation is purely facilitatory. Within-level interactions are depicted by the boxes and are purely competitive, that is, stronger candidates inhibit the activation of weaker candidates.

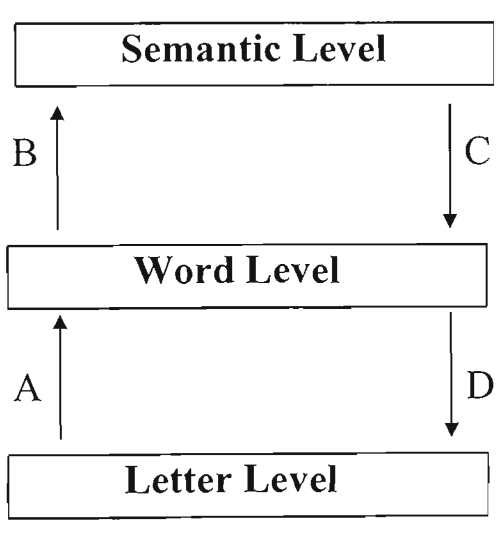


Figure 2.1. Pathways A and B provide bottom-up information whilst pathways C and D provide top-down support for the bottom-up activation (Stolz & Besner, 1996, p. 1168).

Word recognition would be achieved by a stimulus initially activating letter-level representations that flow on in an excitatory fashion to the word level. Within-level competitiveness is assumed to ensure that the most consistent candidates inhibit the activation of those that are less consistent. Similarly, the word level activates consistent

information at the semantic level. Information thus far has proceeded from the letter level to the semantic level; activation has been fed bottom-up.

The bi-directional nature of information processing between levels means that top-down processing can provide support for activation flowing bottom-up, but only in an excitatory fashion. Therefore, semantic associates activated through bottom-up processing can activate word level representations for these semantic associates via top-down processing. Within-level competitiveness for the concurrent information, from top-down processing at the semantic level and bottom-up information from the letter level, are assumed to provide greatest activation for the presented word. Similarly, top-down information regarding the active word-level representation is fed to the letter level. Bottom-up support and within-level competitiveness again are assumed to produce the strongest activation for the letters that were initially presented.

Stolz and Besner (1996) claimed that, although the McClelland (as cited in Coltheart, 1987) model included a semantic level, it did not specify the manner in which representations are activated, nor how they are represented. Semantic-level activation is commonly assumed to result in spreading activation within the semantic level, activating semantically-related concepts (Collin & Loftus, 1975; Morton, 1969; Neely, 1977, as cited in Besner & Humphreys, 1991). However, this cannot be the case in the McClelland (as cited in Coltheart, 1987) model because it assumes that within-level activation is purely competitive. That is, no facilitatory links exist within each level of representation. Therefore, the model has difficulties explaining the facilitation for a target preceded by an associated prime (semantic priming) because preactivation of semantic associates is assumed to be crucial for semantic priming to occur. That is, a word activated in the

semantic system cannot facilitate semantically-associated words as described in the spreading activation account of priming outlined in the previous chapter.

Stolz and Besner (1996) suggested that semantic priming can be accounted for by assuming between-level spreading activation of associates at the word and semantic levels. That is, the word-level representation activates its semantic-level representation and also activates representations of semantic associates at the semantic level. This is consistent with the model's assumption of purely-excitatory interactions between levels.

2.6. DUAL ROUTE CASCADED MODEL (DRC)

The Dual Route Cascaded model of visual word recognition and reading aloud used the IAC model as the starting point, and in doing so inherited some of the characteristics and assumptions of the IAC model. The main ones are that representations are local (i.e., that each concept is represented as a node), and that semantic-priming is the result of a node coming closer to its threshold level due to preactivation. The flow of activation in the model occurs in a cascading manner - once any degree of activation occurs in a module, it flows through to later modules. Another theoretical choice was the use of grapheme-phoneme correspondence (GPC) rules to specify the nonlexical reading route. These rules represent the letter or letter sequence corresponding to each single phoneme, for example the *igh* in *high* (Coltheart, Rastle, Perry, Langson, & Ziegler, 2001). The basic architecture of the Dual Route Cascaded model is illustrated below in Figure 2.2.

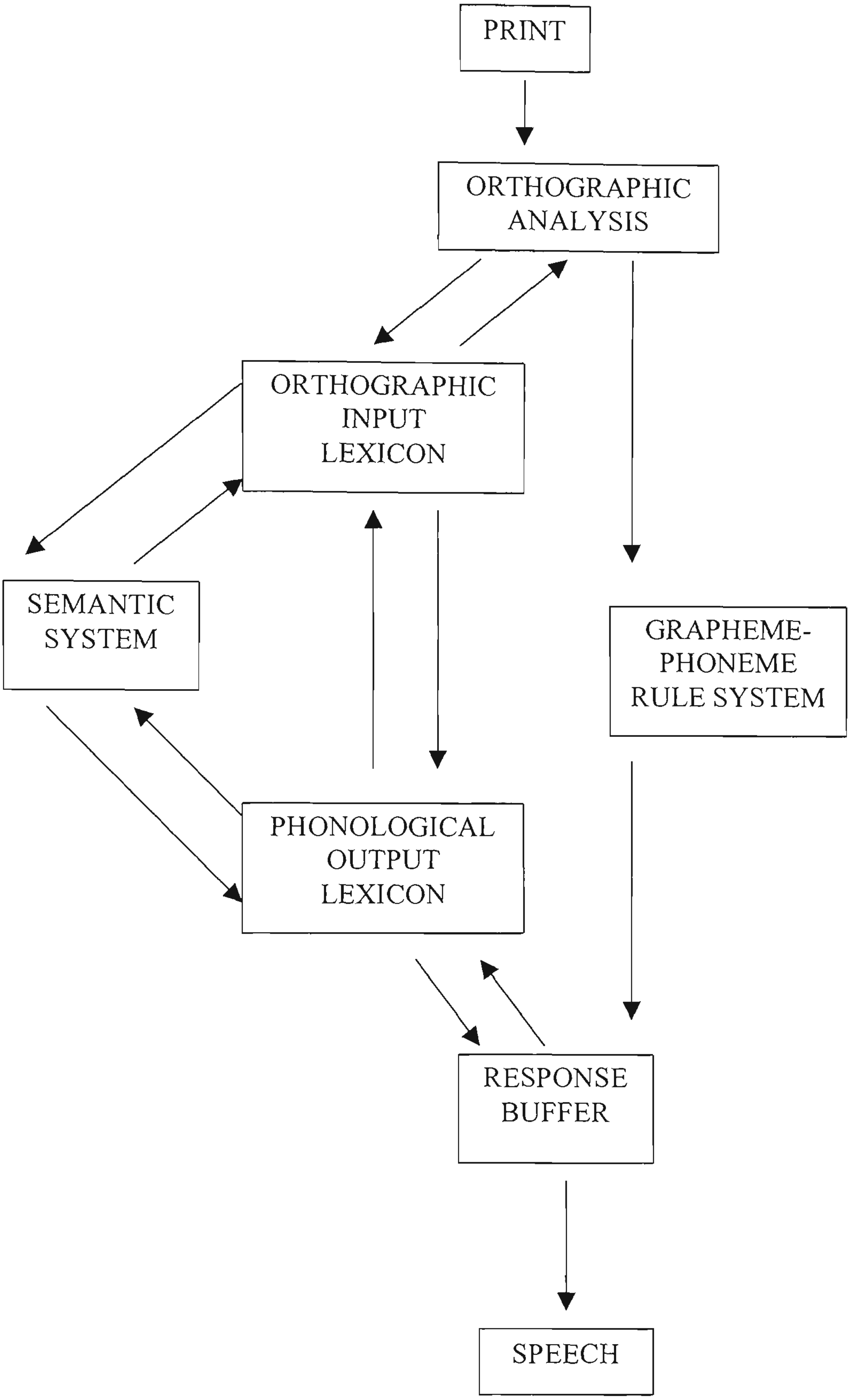


Figure2.2. Basic architecture of the Dual Route Cascaded model of visual word recognition and reading aloud proposed by Coltheart, Rastle, Perry, Langson, and Ziegler (2001).

The initial process of visual word recognition requires identification of the letters. The module which deals with this aspect of processing is the *orthographic analysis* module. Bi-directionally connected to this module is the *orthographic input lexicon*. This lexicon contains the spellings of all the words a skilled reader knows, forming a 'mental dictionary'. This module is therefore able to distinguish words from nonwords. The module called the *semantic system* is bi-directionally connected to the orthographic input lexicon. The meanings of words are represented in this module. The *phonological output lexicon* is bi-directionally connected to the semantic system, enabling the system to speak words. From this point the system has one route by which words can be read aloud.

The second route is provided by the *grapheme-phoneme rule system* module, which enables the system to speak nonwords by processing letter information from the *orthographic analysis* module and converting the letter string into a phoneme string by using the grapheme-phoneme correspondence rules. The information is then transferred to the *response buffer*. Information is transferred between these modules in a serial manner.

The system accounts for the production of written language by bi-directionally connecting the *orthographic output lexicon* to the *semantic system* so that the written form of a word can be established by taking into account the semantic constraints. The *phonological output lexicon* is bi-directionally connected to the *response buffer* in order to temporarily hold information until the word has been produced in its entirety. The framework of the model dealing with recognition and comprehension of spoken language and objects has not been considered here.

2.7. SUMMARY

In summary, traditional box and arrow verbal models of visual word recognition have been developed into computational models. The main assumptions adopted by the DRC model are that representations are local rather than distributed and that processing is cascaded rather than threshold. Current computational attempts at modelling visual word recognition and reading aloud specify the functional architecture and then use learning algorithms to adjust the strength of connections between prespecified modules of the model.

In relation to this thesis, the important aspect of these models is the functional architecture, because it provides a framework for interpreting the experimental findings. Cognitive processing has been conceptualised in a variety of ways that combine aspects of bottom-up and top-down processing. Early models of language processing used multiple modules to represent different aspects of cognitive processing. The functional architectures of more recent models still require assumptions regarding representation and activation. Representations are either local or distributed, and processing is threshold or cascaded. The major shift in thinking has been the development of models that are not based on the concept of the logogen. This shift has allowed processing to be conceptualised in an interactive, parallel and distributed manner. Such models as the DRC still maintain a localist notion of processing, but incorporate networks to perform distinct cognitive tasks using interactive, parallel and distributed activation of subprocesses. The following chapter will focus on the anatomical substrates underlying cognitive operations which are often thought to be anatomically and functionally distinct (Posner & Petersen, 1990).

CHAPTER 3

ANATOMY OF READING

The contribution of the neuroanatomical approach to the understanding of reading shall be considered in order to place the event-related potential (ERP - voltage fluctuations recorded at the scalp) findings of this thesis in context with other research techniques, such as intracranial electrode studies, functional magnetic resonance imaging (fMRI), lesion studies and positron emission tomography (PET). The evidence reviewed will be that pertaining to word-form recognition, and semantic and comprehension processes associated with reading. It should be acknowledged that the immature nature of the functional neuroimaging research has brought criticism, particularly regarding the disparity between experimental paradigms, which has made it difficult to compare results between studies.

3.1. LESION STUDIES

Dyslexia or *alexia* refer to disorders associated with language processing, which can be developmental or acquired. Alexia is referred to as *acquired dyslexia*, resulting from a lesion to the brain. When dyslexia has no acute neurological history, and is evident from early childhood, it is called *developmental dyslexia*. These disorders are often used to establish a correlation between brain anatomy and function in relation to the underlying processes of normal reading. The difficulties arising from using such studies need to be addressed. In general, lesion studies attempt to establish the cortical function of localised structures, but lesions are often not specific, and the damage tends to be heterogenous, making it difficult to establish the overall function of a localised cortical structure. The correlation of brain anatomy with function may also be hindered by cortical plasticity.

This refers to the ability of the brain to functionally reorganise when a brain lesion has occurred. Under these circumstances, attributing brain function to anatomical structures can be ambiguous. Despite the problems associated with using these studies, many advances have been made in our understanding of the underlying processes of normal reading. An example of this is the word-recognition model proposed by Ellis and Young (1988).

3.1.1. LESION MODEL

Ellis and Young (1988) used information regarding specific neuroanatomical lesions and selective cognitive impairments to form the basic framework for a model of word recognition. This framework supports localized components of processing. The model has the serial, hierarchical and modular characteristics of the classical models of brain functioning. A schematic representation of the process involved in visual word recognition is presented in Figure 3.1.

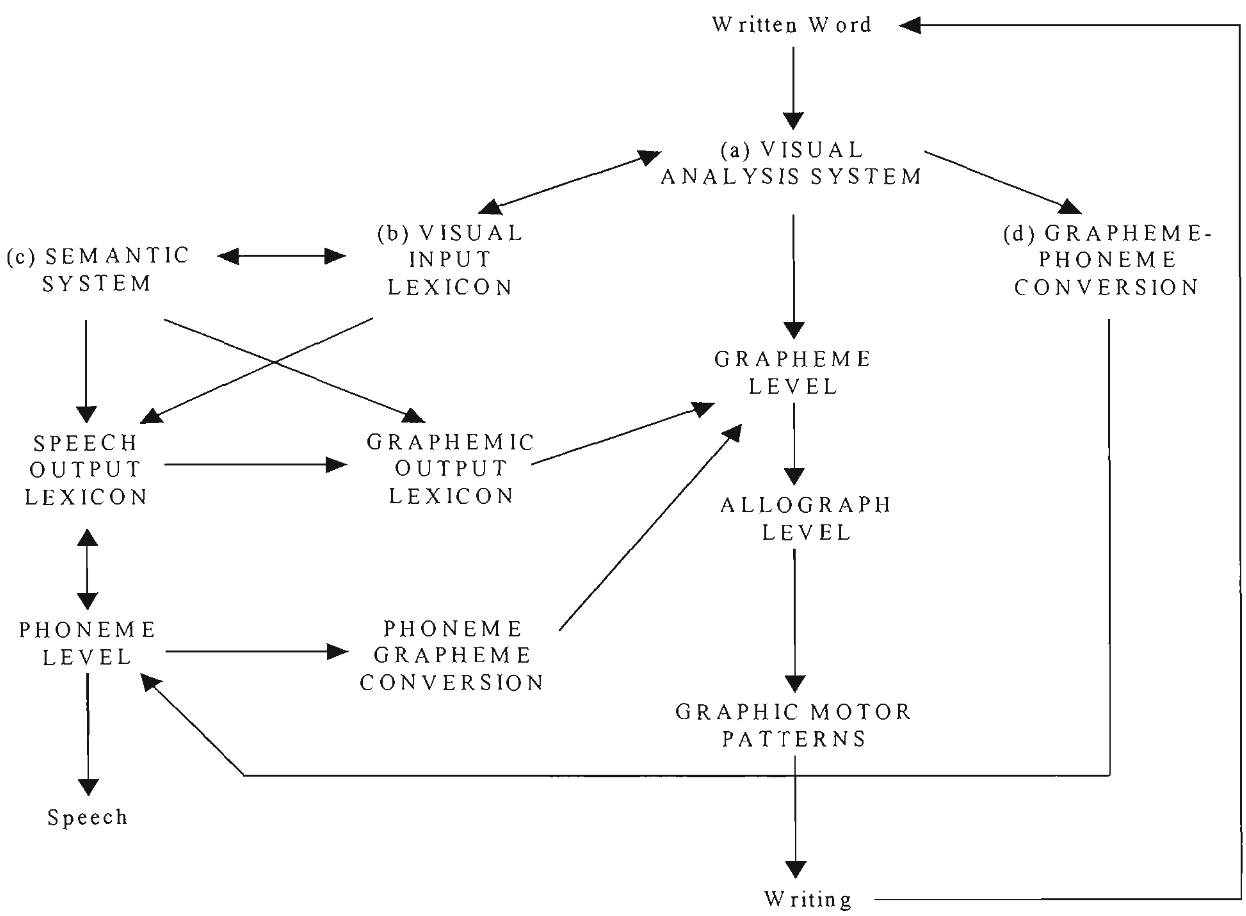


Figure 3.1 Model for the recognition and production of written words (from Ellis & Young, 1988, p. 222).

The first component in this model is (a) the *visual analysis system.* This involves identifying individual letters in a word, distinguishing their position within that word, and perceptually grouping letters belonging together as part of the same word. The system is able to identify several letters simultaneously and in parallel. The model assumes that once a reader identifies a string of letters, which forms familiar words, then these words activate (b) the *visual input lexicon*. This component can form responses to unfamiliar words by accessing representations of a visually-similar real word. Once a reader has learned to recognise many words, each word will be represented in their visual input lexicon.

The letter recognisors in the visual analysis system provide input to the visual input lexicon, which indicates that a word has been seen, but for a word to be understood its semantic representation must be activated in (c) the *semantic system.* This module contains information about the meaning of the word. Once a word is understood then its spoken form can be activated through the speech-output lexicon, allowing the normal speech production of that word.

The process of the model labelled (d) *grapheme-phoneme conversion* (letters to sounds) involves the conversion of letter strings into phoneme strings. A possible sublexical route is proposed which enables processing from letter recognition to speech output by dividing a word into letters or groups of letters and translating this visual input into phoneme strings. In this way, unfamiliar words and nonwords can be processed. The skilled reader would rarely use this route, but it is particularly useful for children or unskilled readers. This route enables readers to sound out words, even though they may not be represented in the visual input lexicon.

The theoretical development of this model has relied, in part, on examining the patterns of abilities and impairments in individuals with dyslexia. Therefore, different patterns of reading impairments will be briefly reviewed and related to the theoretical model presented in Figure 3.1.

Much of the literature is concerned with providing an account of the symptomatology associated with reading disorders as a result of brain damage, or *acquired dyslexia.* The distinction is made between *peripheral* and *central* acquired dyslexia. The former affects the early visual processes associated with the visual analysis system, that is, letter

recognition, coding for position, and grouping letters. Disruption to this system may account for the symptoms exhibited by *neglect* and *attentional* dyslexics and *letter-by-letter* readers.

Neglect dyslexics are unable to identify letters at the beginning or end of words, whereas *attentional dyslexics* show a problem with grouping letters. They erroneously substitute groups of letters from other words presented simultaneously. A letter-by-letter reader has lost the ability to identify letters of a word simultaneously and in parallel. In order for these people to identify a word, each letter must be identified separately. One theory is that the visual input lexicon can no longer access familiar words, and word recognition is accomplished by a reversed use of the person's intact spelling system (Ellis & Young, 1988). However, this postulated reverse use of the spelling system is not explained or elaborated.

Central dyslexia affects word recognition, comprehension and naming processes, and processes dealing with unfamiliar words and nonwords. Therefore, it appears to involve disruption to the visual input lexicon (*visual dyslexia*), semantic system (*semantic access dyslexia)* and the grapheme-phoneme conversion components of the model (*phonological dyslexia* and *deep dyslexia* where phonological and deep dyslexics display overlapping symptoms).

Visual dyslexia is associated with visual errors which arise due to impairment of the visual input lexicon. Patients with this deficit might read the word *calm* as *clam*. Impairment in the connection between the visual input lexicon and the semantic system may account for the ability of someone with semantic access dyslexia to correctly perform

a visual lexical decision, such as distinguishing between words and nonwords. However, they have difficulty understanding many written words due to their inability to access meaning from the semantic system. The grapheme-phoneme conversion component of the model appears to be impaired in phonological and deep dyslexics who are able to read aloud familiar words better than unfamiliar words or nonwords.

3.2. VISUAL WORD FORM

Dejerine (1891, 1892; as cited in Albert, 1979) suggested that the left angular gyrus was specific to the visual word form. Support for the claim stems from lesions to the area resulting in *alexia* (an inability to read) with *agraphia* (an inability to write), but not emerging from *aphasia* (focal brain damage in Wernicke's and/or Broca's areas of the brain) (Damasio & Geschwind, 1984).

PET studies, in which subjects passively viewed single words relative to a fixation point, have shown increased blood flow in bilateral extrastriate and occipital striate visual areas (Petersen, Fox, Posner, Mintun, & Raichle, 1989). Right hemisphere extrastriate activation was elicited when subjects viewed orthographically-legal nonwords (pseudowords), illegal consonant strings, and false fonts (letter-like strings) (Petersen et al., 1990). Processing in this region was common to all stimuli, and therefore most consistent with pre-lexical processing of visual features. Activation of the left hemisphere medial extrastriate cortex occurred for words and pseudowords, but not illegal consonant strings. This indicated that activation in this region was specific to word-like stimuli. It was concluded that processing in this region reflected the visual organisation of letters (visual word form) in order to achieve word recognition.

Howard, Patterson, Wise, Brown, Friston, Weiller, and Frackowiak (1992) disputed the location of the region involved in visual word form processing. In a PET study, subjects were required to read words aloud or say 'crime' in response to presentation of false-font stimuli. The latter condition was used because it was thought to provide a more appropriate control condition than passively viewing words, given the motor activity associated with reading in the initial task. Activation occurred over the left posterior middle temporal cortex, but not over the left medial extrastriate cortex as described above. It was therefore concluded that the left posterior middle temporal cortex reflected processing of the visual word form. It is possible that the discrepancy in results may reflect the difference in tasks. The task used by Howard et al. (1992) required a verbal response, which may have engaged different processing from the passive viewing tasks used by Petersen et al. (1989, 1990).

Price, Wise, Watson, Patterson, Howard and Frackowiak (1994) replicated the paradigm used by Howard et al. (1992), varying the stimulus exposure. Stimuli exposed for 1000 msec, as used by Howard et al. (1992), failed to elicit increased blood flow in the left posterior middle temporal cortex. However, increased blood flow did occur in this region when stimulus exposure duration was 150 msec. Activation also incorporated the left posterior temporal and inferior parietal lobes. It was concluded that the left middle temporal area was associated with word-form processing. They also replicated the paradigm used by Petersen et al. (1990), again varying the duration of stimulus exposure. At the stimulus exposure of 150 msec, increased blood flow in the left medial extrastriate cortex was not elicited to passively-read words relative to false-font stimuli. However, when stimuli were presented for 1000 msec, words elicited increased blood flow in the left medial extrastriate cortex region, marginally posterior to that reported by Petersen et

al. (1990). This again implicates the left medial extrastriate cortex in visual word recognition. These findings illustrate that the type of processing used may vary with different stimulus-exposure durations.

Intracranial ERP studies have shown activation of the medial inferior occipital and temporal lobes by letter strings and words. Such stimuli elicited a negative potential peaking at approximately 200 msec. The potential was insensitive to semantic-priming and other stimuli such as checkerboards, complex objects and faces (Nobre, Allison, & McCarthy, 1994; Nobre & McCarthy, 1994). The sensitivity of the potential to visual letters implies pre-lexical processing. These findings support the medial occipital temporal area being involved in word-form recognition.

Overall, it would appear that the synthesis of letters into a visual word form involves a network of areas lateralized in the left hemisphere. The more posterior medial activation seems to reflect pre-lexical processing of letters, and the more anterior medial activation appears to be associated with the processing of orthographically-legal letter-strings and words.

3.3. SEMANTIC PROCESSING

3.3.1. WERNICKE'S AREA

Wernicke's aphasia is associated with the reading disorder *aphasic alexia*, characterised by word substitution, the association of words and phrases in a meaningless manner, and the production of meaningless words. In general, the ability of Wernicke's aphasics to comprehend language is severely impaired (Albert, as cited in Heilman & Valenstein, 1979). This emerges due to damage to the posterior section of the superior temporal gyrus

and the junction of the temporal and parietal lobes. In terms of the Brodmann area classification, it has been implicated with areas 22, 37, 39 and/or 40 (Selnes, Knopman, Niccum, & Rubens, 1985). It was suggested that aphasic alexia could be a syndrome of alexia with agraphia, with the extent of damage to Wernicke's area and the angular gyrus determining the type and extent of the reading impairment. The specific nature of language deficits due to lesions in Wernicke's area tends to support Benson's (1979) claim that Brodmann area 37 could be a lexicon or 'word dictionary'. This claim was based on studies of pure word selection anomia (inability to find the name of common objects) stemming from a variety of brain lesions.

Blumstein, Milberg and Shrier (1982) reported that Wernicke's aphasics showed semantic-priming effects even though they were unable to perform a semantic judgement task and displayed semantic paraphasias in speech. Semantic paraphasias are incorrect word selection, when a word is substituted for an intended word. This showed that lesions to Wernicke's area do not necessarily result in an inability to process word meaning. Milberg, Blumstein, Katz, Gershberg and Brown (1995) suggested that the discrepant results reflected an inability to perform the strategic processing required in a particular task rather than an inability to process the meaning of words. This implied that lesions to Wernicke's area affect complex semantic processing and not the automatic activation of the meaning associated with a single word. This claim had been supported by lesion studies which associated semantic representation with specific regions. Lesions to the prefrontal heteromodal cortex have resulted in difficulty retrieving words associated with a specified subordinate category, while anterior middle temporal lesions are often characterised by a selective inability to recognise objects associated with a particular semantic category (McCarthy & Warrington, 1986, 1988).

The lesion studies described earlier have implicated Wernike's area with semantic processing which is more complex than accessing a single word's meaning. Support for this claim has emerged from PET and fMRI studies which have reported activation in regions of the temporal lobe associated with sentence and story comprehension tasks, the Controlled Oral Word Association Task (COWAT, a word association fluency task that requires subjects to produce words beginning with a given letter within a time limit), and use-generation tasks (for example, when presented with the word 'cake', the subject might respond with 'eat') (Bottini, Corcoran, Sterzi, Paulesu, Schenone, Scarpa, Frackowiak, & Frith, 1994; Friedman, Kenny, Wise, Wu, Stuve, Miller, Jesberger, & Lewin, 1998; Mazoyer, Tzourio, Frak, Syrota, Murayama, Levrier, Salamon, Dehaene, Cohen, & Mehler, 1993; Raichle, Fiez, Videen, MacLeod, Pardo, & Petersen, 1994).

In an fMRI study, Friedman et al. (1998) required subjects to perform the COWAT vocally and silently. Letters were presented in the auditory modality and subjects were required to produce as many words as possible beginning with a particular letter. They reported activation of Brodmann area 21 and 37 associated with Wernicke's area. Area 21 was implicated with phonetic processing and searching the phonetic lexicon, and possibly associated with semantic processing. Area 37 was implicated with both phonetic and orthographic representation of the target letter, orthographic lexicon search and semantic association. It is suggested that areas 21 and 37 could represent lexicons, supporting the claims of Benson (1979) described earlier.

Intracranial electrodes in the anterior fusiform gyrus have recorded a positive potential with a peak latency of approximately 400 msec (P400). It was shown that the anterior temporal P400 is sensitive to the semantic content of sentences and single words (Nobre,

Allison & McCarthy, 1994; Nobre & McCarthy, 1994). Subjects were presented with a variety of stimuli, including checkerboards, illegal nonwords, faces, words containing semantic content (content words) and function words. The P400 potential was elicited only by content words. Also, semantic priming in a single word or sentential context was shown to attenuate P400 amplitude. This implies that the anterior temporal region of the inferior temporal lobe is associated with conceptual or semantic processing of words.

Research has reported that lesions to the left anterior temporal lobe are characterised by an inability to name specific classes of objects, whilst conceptual knowledge and language remain intact (Anderson et al., 1992). This network is thought to mediate between the language and conceptual systems. Support for this mediating network comes from 'direct dyslexia', characterized by intact speech production without comprehension of the utterance (Schwartz, Saffran, & Marin, 1980), and more directly from transcortical sensory aphasia, which is associated with lesions that disconnect the primary speech areas from the posterior association cortex. This results in an inability to comprehend speech or generate speech which is meaningful (Kertesz, 1979).

3.3.2. FRONTAL AREAS

PET, fMRI and depth-electrode studies have implicated the left prefrontal cortex in semantic processing. These studies often refer to the middle frontal gyrus and the inferior frontal gyrus. The former is referred to as the dorsolateral prefrontal cortex (DLPC, Brodmann area 46) and the latter as the anterior inferior prefrontal cortex (AIPC, Brodmann areas 44, 45, 47). Studies have shown a functional dissociation between the anterior inferior prefrontal cortex and the more anterior dorsolateral prefrontal cortex (Buckner, Raichle, & Petersen, 1995), and therefore these regions will be considered

separately.

3.3.2.1. DLPC

Abdullaev and Bechtereva (1993) used depth electrodes in the left prefrontal cortex (Brodmann areas 46 and 10) of a patient whilst performing a lexical-decision task. Cells in the DLPC showed differences in activation to words compared with orthographically-legal nonwords (pseudowords), which indicated sensitivity to word meaning. These cells also showed differences in a discrimination task regarding visually-concrete and abstract words. However, mental arithmetic and object naming failed to produce task-related responses. Therefore, these cells showed functional selectivity in the semantic processing of words. This was supported by an fMRI study assessing the effects of imagery and semantic relatedness on cued retrieval of word pairs. Differences in the activation of the left DLPC were reported when comparing nonimageable and imageable recall. Frontal activity was also shown to increase bilaterally as semantic association decreased within the imageable and nonimageable groups (Fletcher, Shallice, Frith, Frackowiak, et al., 1996).

PET studies reporting increased DLPC activation have been associated with task demands that require a general response generation that is intrinsic or internally driven, as opposed to stimulus-determined responses. It has been shown that the tasks do not have to be of a specifically linguistic or semantic nature.

The PET studies using word generation and retrieval required responses that were intrinsic or internally driven. Increased DLPC activation in these tasks has been associated with semantic processing (Buckner, Raichle, & Petersen, 1995; Frith, Friston, Liddle, &

Frackowiak, 1991a; Petersen et al., 1989; Warburton, Wise, Price, Weiller et al., 1996). However, Pardo, Pardo, Janer and Raichle (1990) reported no increased activation of the DLPC using the Stroop task, which is stimulus driven and assumed to require attention and semantic processing. The main difference between the tasks is that responses associated with the Stroop task are stimulus driven whereas responses in the word generation and retrieval tasks are internally driven. Frith, Friston, Liddle and Frackowiak (1991b) required subjects to either respond with the semantic opposite of presented stimuli or perform a non-semantic word-generation task. Increased activation of the DLPC was only elicited by the non-semantic word-generation task. It was concluded that activation of the DLPC was not specific to linguistic or semantic processing, but rather reflected a general 'willed action' or internally-driven response.

However, Petrides et al. (1993a, b) reported increased activation of the DLPC in both externally- and self-generated tasks. It was suggested that this cortical region was functionally associated with the processes of working memory and not willed action. This interpretation has been supported by Mangels, Gershberg, Shimamura and Knight (1996), who reported that patients with left DLPC lesions exhibited impaired recognition for remote memory relative to matched controls. The Famous Faces Test was administered with semantic and phonemic cues, but there was still a deficit in the recall performance of lesion patients. It was concluded that remote memory impairment associated with lesions of the left DLPC may be the result of an inability to strategically search memory.

Further evidence was reported by Mangels (1997) in experiments assessing strategic processing and memory for temporal order in patients with lesions in the DLPC. Such patients exhibit deficits for temporal order, and the research attempted to determine

whether this was the result of impaired automatic encoding of temporal information or deficits in strategic processing. Subjects were given lists of semantically-related and unrelated words and were required to learn them under intentional or incidental conditions. Tests were then performed on temporal order reconstruction of the lists. It was reported that intention to learn the lists did not influence the memory for temporal order in patients with DLPC lesions, compared with semantic relatedness, which did influence memory for temporal order in patients. Similar encoding manipulations were also used to assess free recall and recognition. Memory for temporal order in the lesion patients was found to be dissociable from item memory. It was concluded that lesion patients automatically encode information related to temporal order but there is a deficit in the strategic processing of this information in relation to memory search.

Similarly, Fletcher, Shallice and Dolan (1998) used encoding tasks requiring subjects to organise information based on semantic attributes. Left DLPC activation was maximal when subjects encoded information by generating organisational structure relative to encoding associated with presented information that was already organised. When a concurrent distraction task was used to disrupt processing, activation was attenuated in the task requiring organisational processing, but not in the other encoding tasks where structure was already known. It was concluded that the functional specificity of the left DLPC was to facilitate encoding by creating organisational structure using abstraction of relevant semantic attributes.

3.3.2.2. AIPC

Activation of the left AIPC has been shown to be associated consistently with analysis of word meaning, and therefore functionally implicated with semantic processing. Explicit

semantic verb-generation and monitoring tasks have been reported to elicit increased activation in this area (Petersen et al., 1989). However, Posner, Petersen, Fox and Raichle (1988) reported increased activation in the AIPC when subjects were required to semantically categorize visual words in the absence of a verb response. Increased activation of the AIPC has been reported in a variety of linguistic tasks, word listening (Mazoyer, Tzourio, Frak, Syrota, Murayama, Levrier, Salamon, Dehaene, Cohen, & Mehler, 1993), silent verb generation (Wise, Chollet, Hadar, Friston, Hoffner, & Frackowiak, 1991), single-word reading and lexical decision (Price, Wise, Watson, Patterson, Howard, & Frackowiak, 1994), and verbal and pictorial repetition priming (Wagner, Desmond, Demb, Glover, & Gabrieli, 1997). Wise et al. (1991) failed to show increased activation of the AIPC in silent word-reading tasks, and it was concluded that the APIC appears to be sensitive to the level of attention to semantic analysis.

Gabrieli, Desmond, Demb, and Wagner (1996) used fMRI to investigate semantic memory processes in the frontal lobes. It was reported that semantic encoding of words resulted in greater activation in the left inferior prefrontal cortex (IPC) relative to perceptual encoding. Also, repeated semantic encoding of words resulted in decreased activation in left IPC relative to that associated with initial semantic encoding. This was assumed to reflect semantic repetition priming. Repetition priming was defined as the implicit retrieval of memory achieved during initial semantic encoding of a word. It was concluded that the left IPC may subserve semantic encoding in working memory. This was supported by Wagner, Desmond, Demb and Glover (1997) in a similar experiment assessing activation in the left IPC during initial and repeated semantic processing of words and pictures. As in the previous experiment, repeated semantic processing resulted in decreased activation in the left IPC. This decrease in activation was greater for words

than pictures, indicating that semantic analysis occurred regardless of the perceptual form of the stimuli. It was concluded that the left IPC may function as a 'semantic executive system', retrieving long-term conceptual knowledge considered appropriate to task performance.

The literature involves a wide variety of paradigms, and overall, the DIPC appears to be associated with creating organisational structure. This may involve the use of semantic attributes, whereas the AIPC reflects semantic analysis and is sensitive to task demands that vary attention in relation to semantic analysis.

3.4. ATTENTION

The anterior cingulate on the frontal midline has often been associated with tasks requiring active attention or responses. Tasks requiring an immediate motor response, such as reading aloud or button press, tend to result in activation closer to the motor areas. The subtraction method has been used to eliminate motor activity. This technique requires a paired subtraction of the PET images of brain blood flow generated by the task and control. Tasks not requiring a motor response have resulted in activation of the anterior cingulate (Petersen, Fox, Posner, Mintun, & Raichle, 1988, 1989; Posner, Petersen, Fox, & Raichle, 1990).

The conflict between the ink colour and the word name in the Stroop task has been used extensively to assess attention. A PET study using the classic Stroop task has shown activation in the anterior cingulate (Pardo, Pardo, Janer, & Raichle, 1990). Variations of the Stroop task have also produced activation in the cingulate (Bench, Frith, Grasby, Friston, Paulesu, Frackowiak, & Dolan, 1993; George, Ketter, Parekh, Rosinsky, Ring,

Casey, Trimble, Horwitz, Herscovitch, & Post, 1994).

Activation in the cingulate is not modality specific, as many nonlinguistic tasks with demands assumed to engage controlled processing have resulted in activation of this region (for example, visual classification: Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990; Posner & Petersen, 1990).

3.5. COGNITIVE ANATOMICAL FRAMEWORK

This section will attempt to form a framework organising cognitive functioning and associated anatomical regions based on the evidence provided above (see Figure 3.2.). The structure of the framework will be based on that of Petersen et al. (1988).

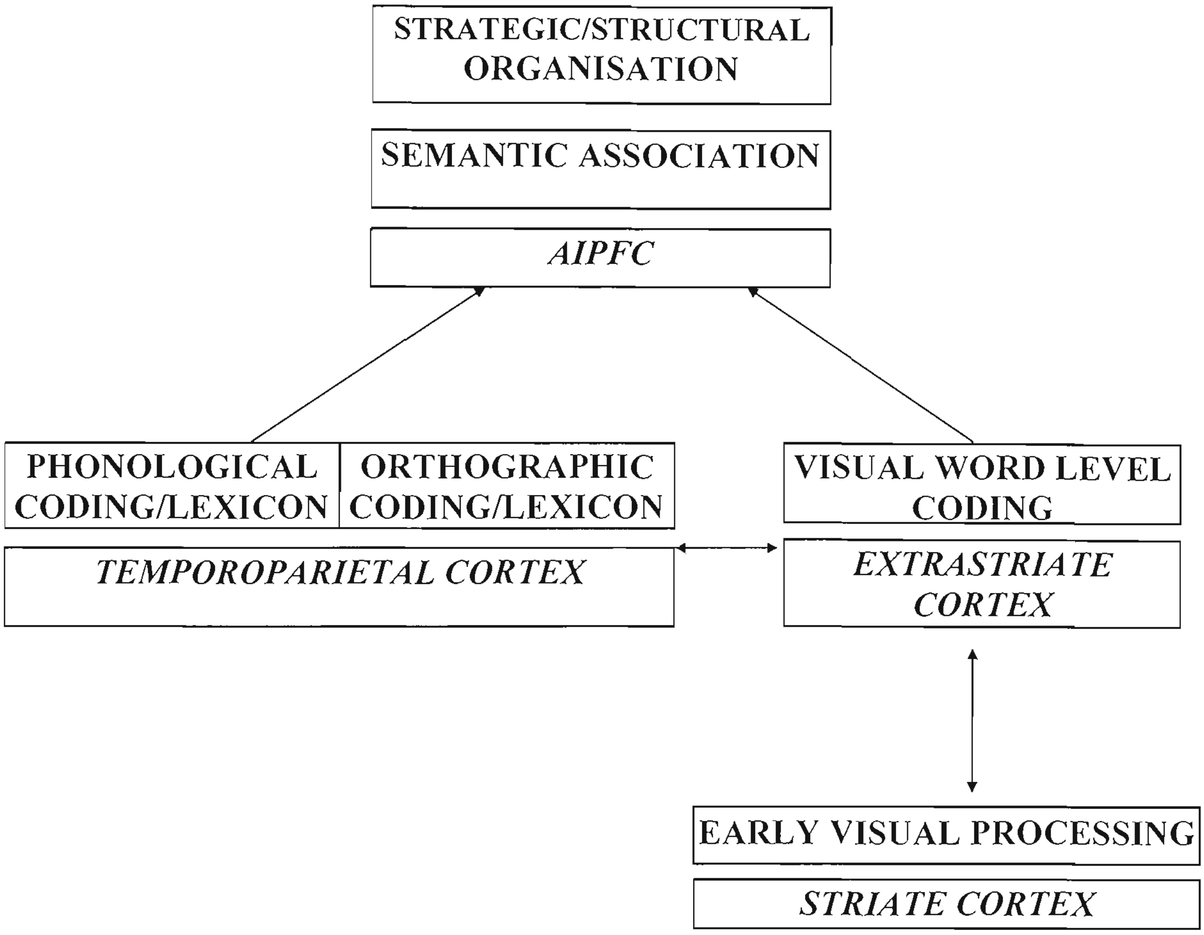


Figure 3.2. This framework is based on that of Petersen et al. (1988) and provides a summary of the literature reviewed by organising cognitive functioning and associated anatomical regions.

Presentation of visual stimuli and visual imagery results in activation of the striate cortex (Kosslyn, Alpert, Thompson, Maljkovic, Weise, Chabris, Hamilton, Rauch, & Buonanno, 1993; Petersen, Fox, Posner, Mintun, & Raichle, 1988; Petersen, Fox, Snyder, & Raichle, 1990). The visual word form appears to directly activate semantic codes and also phonological codes. The temporoparietal cortex has also been described as a possible cortical location of the lexicons (Benson, 1979; Friedman, Kenny, Wise, Wu, Stuve, Miller, Jesberger, & Lewin, 1998; Howard, Patterson, Wise, Brown, Friston, Weiller, & Frackowiak, 1992). Processing of information regarding semantic association appears to be localised in the AIPC, and tasks which require structural or strategic semantic processing have been shown to also activate the left DLPC (Fletcher, Shallice, & Dolan, 1998).

Friedman, Kenny, Wise, Wu, Stuve, Miller, Jesberger and Lewin (1998) suggested that the limitation of proposing an anatomical framework is that each cognitive component specified in the model appears reliant on multiple brain regions. Distributed networks appear to be recruited by cognitive modules. For example, the AIPC, DLPC, superior temporal sulcus, middle temporal gyrus and angular gyrus have all been implicated in semantic processing (Binder, Frost, Hammeke, Rao, & Cox, 1996; Binder, Rao, Hammeke, Friedman, Kenny, Wise, Wu, Stuve, Miller, Jesberger, & Lewin, 1998; Binder, Rao, Hammeke, Frost, Bandettini, Jesmanowicz, & Hyde, 1995). The concept of cognitive modules and distributed networks is consistent with the principles of information processing associated with the parallel distributed processing framework (PDP) (McClelland, as cited in Meyer & Kornblum, 1992; Rumelhart, Hinton, & McClelland, as cited in Rumelhart, McClelland, and the PDP Research Group, 1986).

3.6. SUMMARY

In the previous chapter models of language processing provided a functional architecture for cognitive operations. The purpose of this chapter was to describe the anatomical regions associated with those cognitive operations and establish a basic cognitive-anatomical framework. The literature illustrates that regional cortical activity is sensitive to task demands. The key finding is that individual cognitive functions seem to be associated with multiple brain areas, and these brain areas appear to be functionally specialised. This suggests that cognitive operations function in a distributed network. In this context, the following chapter will focus on the contribution of linguistic event-related potentials to our understanding of the neural organization of reading processes.

CHAPTER 4

ERPs

Event-related potentials are voltage fluctuations recorded at the scalp, and reflect synchronous neuronal activity associated with cognitive, sensory and motor events (Hillyard & Picton, as cited in Plum, 1987; Kutas & Hillyard, 1983). The ERP waveform is triggered by an event such as a visual stimulus and consists of positive and negative voltage fluctuations, the voltage fluctuations recorded at the scalp are averaged to improve the signal to noise ratio. The components associated with these voltage fluctuations reflect the temporal progression of processing. The early components reflect sensory activity followed by higher level cognitive processes and behavioural response-related processes. ERP components are usually labelled in relation to polarity and peak latency within the ERP waveform. The main advantage of using ERP measures is that they provide excellent temporal resolution compared with traditional behavioural methods and other brain imaging techniques such as PET and fMRI. The majority of the following section will describe components associated with the field of averaged visual ERPs.

4.1. LINGUISTIC EVENT-RELATED POTENTIALS

4.1.1. N400

An N400 is a negative deflection in the ERP waveform varying in peak latency from 300-550 ms post stimulus onset. Open class words have been shown to elicit an N400 component (Kutas & Van Petten, 1994). This should be distinguished from the priming

effect on N400 amplitude. It has been reported that the amplitude of the N400 is modulated by semantic context. For example, the N400 amplitude is larger when a target word is preceded by a semantically-unrelated word compared to when it is preceded by a related word; this is commonly referred to as the N400 effect (Holcomb, 1988; Holcomb & Anderson, 1993; Kutas & Hillyard, 1989).

4.1.1.1. SEMANTIC INCONGRUITY AND LINGUISTIC CONTEXT

The N400 ERP component was initially described by Kutas and Hillyard (1980a) in an experiment involving the presentation of sentences with semantically congruous or incongruous terminal words. Incongruous terminal words elicited an additional monophasic negativity, beginning approximately 200 ms after the onset of the terminal word and peaking at approximately 400 ms post-stimulus. The negativity displayed a central-parietal maximum and was largest over the right hemisphere. They concluded that this N400 effect may reflect an attempt to reinterpret the semantically incongruous information (Kutas & Hillyard, 1980a, 1980b, 1982; Kutas, Van Petten, & Besson, 1988). However, Kutas and Hillyard (1984) manipulated cloze probability, the likelihood that a particular word would be used to complete a sentence, and reported that congruous terminal words with a low cloze probability evoked a larger N400 amplitude than words with high cloze probability. Therefore, this effect could not be considered contingent upon semantic incongruity, and it was concluded that the N400 effect reflected the extent to which a word has been primed by preceding context. This interpretation was supported by Van Petten and Kutas (1990), who reported that all content words presented in a congruous sentence elicited an N400 component, and that the amplitude of this component decreased across word position as contextual constraint increased.

Fischler, Bloom, Childers, Roucos, and Perry (1983) also provided support showing that incongruity is not sufficient to elicit an N400 effect. In their experiment, subjects were required to verify four different types of semantic propositions: true affirmative (e.g., 'A robin is a bird'), false affirmative ('A robin is a vehicle'), true negative ('A robin is not a vehicle'), and false negative ('A robin is not a bird'). Terminal words of the true negatives and false affirmatives elicited an N400. They concluded that the N400 was independent of the contextual congruity of the terminal word and did not reflect the truth or falsity of a sentence. Rather, the degree of semantic association between the content words of a sentence determines the amplitude of the N400 to the terminal word.

The specificity of the N400 effect to semantic incongruity in linguistic contexts is further supported by studies which have shown that non-semantic incongruities such as orthographic, grammatical, syntactic, musical, and geometric anomalies have failed to elicit an N400 effect of the same magnitude as semantic incongruities.

Kutas and Hillyard (1980a, 1980b) reported that orthographic deviations presented visually within a sentence (in the form of oversized bold print) elicited a late positivity rather than an N400. Kutas and Hillyard (1983) presented subjects with prose passages containing semantic and grammatical violations. The grammatical violations consisted of verb tense or the incorrect use of singular or plural noun or verb, and did not involve semantic congruity. They found that the semantic deviations elicited an N400 effect, whereas grammatical violations elicited a much smaller, frontally-distributed negativity. Van Petten and Kutas (1991) assessed whether the N400 was sensitive to syntactic constraint in an experiment which required subjects to read different types of sentences, (i) syntactically legal but nonsensical, (ii) semantically congruous and incongruous

sentences and (iii) random word strings. They reported a reduced N400 in the syntactically legal but nonsensical sentences and random word strings, relative to the semantically-meaningful sentences. It was concluded that the N400 is insensitive to syntactic constraint.

Research has shown the absence of an N400 effect to deviant notes in familiar French melodies and to deviations in a predictable series of geometric figures (Besson & Macar, 1987; Paller, McCarthy, & Wood, 1992). Besson and Macar (1987) suggested that the absence of the N400 reflected the simplicity of their tasks, which could have been completed without any need for further processing beyond the simple mismatch detection.

Although the N400 was originally observed in sentence tasks where semantic expectancies were violated, subsequent research has indicated that the N400 effect can also be reliably elicited during single-word reading tasks, such as a word-pair priming task. These findings led Kutas and colleagues to suggest that the N400 component reflected processing associated with lexical activation rather than semantic incongruity *per se*. These tasks included lexical decision (Bentin, McCarthy, & Wood, 1985; Holcomb, 1988), semantic categorization (Boddy & Weinberg, 1981; Deacon, Breton, Ritter, & Vaughan, 1991; McCarthy & Nobre, 1993; Young & Rugg, 1992) and phonological matching (Kutas & Van Petten, as cited in Ackles, Jennings, & Coles, 1988; Rugg, 1984; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). Word-list paradigms have enabled the investigation of the N400 without confounds of syntactic constraints or complex context which may impact on the results obtained in sentence tasks. Such paradigms have revealed that the N400 is sensitive to the semantic relationship between stimuli. These paradigms include semantic categorization tasks (Boddy, 1981; Boddy &

Weinberg, 1981; Deacon, Breton, Ritter, & Vaughan, 1991; Rugg, Furda, & Lorist, 1988; Young & Rugg, 1992), lexical decision tasks (Bentin, McCarthy, & Wood, 1985; Boddy, 1986; Holcomb, 1988), phonological matching (Kutas & Van Petten, as cited in Ackles, Jennings, & Coles, 1988; Rugg, 1984; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980) and verification tasks (Fishler et al., 1983; Holcomb, 1985; Kounios & Holcomb, 1992).

The N400s elicited in word-list tasks are similar to those elicited in experiments using a sentential context. Bentin et al. (1985) used a lexical-decision task in which subjects were presented with a continuous list of words interspersed with pseudowords. Words in the list were either primed by a preceding semantic associate or remained unprimed. The N400 amplitude was found to be more negative for unprimed words than for primed words. It was concluded that this negativity was similar to that elicited by incongruous terminal words in a sentential context as reported by Kutas and Hillyard (1980a, 1980b, 1982, 1984).

4.1.1.2. COGNITIVE FUNCTIONING AND THE N400

There is growing support to suggest that the N400 may reflect processing at the conceptual level. St. George, Mannes, and Hoffman (1994) reported that the N400 was sensitive to the coherence of the global context. Ambiguous text was presented either preceded by a title which disambiguated the text (globally coherent), or presented without a title (globally noncoherent). Words in the globally-noncoherent texts elicited an enhanced N400 relative to those words presented with a coherent global context. This paradigm enables investigation of the N400 without any contribution from syntactic attributes or lexical-level semantic-priming between word pairs because identical texts were used in the titled and untitled conditions. Therefore, it was concluded that the N400

reflects conceptual processing.

This interpretation is supported by studies which have reported that the N400 amplitude effects are not modality specific. The N400 effect has been elicited in the visual modality in a variety of languages (Friederici, 1997), including French (Besson & Macar, 1987), Dutch (Holcomb, 1985), and English (Chwilla, Brown, & Hagoort, 1995). It has also been elicited in the auditory modality (Bentin, Kutas, & Hillyard, 1993; Holcomb & Neville, 1990), tactile modality (Kutas, Neville, & Holcomb, as cited in Ellingson, Murray, & Halliday, 1987) and in priming tasks across modalities (Holcomb & Anderson, 1993).

The fact that the N400 effect is not unique to linguistic stimuli is further evidence that the N400 may be an index of semantic/conceptual processing. There has been extensive research regarding the processing demand of words relative to that associated with pictures (Barrett & Rugg, 1990; Nigam et al., 1992; Potter, Kroll, Yachzel, Carpenter, & Sherman, 1986; Stelmack & Miles, 1990; Stuss et al., 1983). Nigam et al. (1992) replicated the Kutas and Hillyard (1980a) experiment, replacing the terminal word with a pictorial representation of that word or concept. They made a distinction between the mental lexicon, which stores information about words, and an amodal conceptual system, which represents conceptual knowledge independent of modality. The N400 elicited to incongruous pictures was the same as that to incongruous terminal words. It was concluded that the N400 was sensitive to the semantic relationship between non-linguistic stimuli and is therefore an index of processing related to semantic/conceptual representations.

The research described above indicates that the N400 effect is contingent on semantic processing, not a general response associated with incongruity or mismatch. However, this interpretation of the N400 has been challenged by experiments which have elicited an N400 component in tasks that do not necessarily access semantic information. For example, Stuss, Sarazin, Leech and Picton (1983) recorded N400-like negativity in a mental rotation task, which required subjects to judge whether geometrical figures were identical or mirror images. Research has also shown enhanced N400 amplitude to unfamiliar faces relative to familiar faces in face-recognition tasks (Barrett & Rugg, 1989; Barrett, Rugg, & Perrett, 1988; Bentin & McCarthy, 1994), to musical deviations in a sample of musicians, but not in non-musicians (Levett & Martin, 1992) and to non-rhyming words relative to rhyming words in a phonological task (Sanquist, Rohrbaugh, Syndulko & Lindsley, 1980). The N400 has also been elicited by orthographically-legal nonwords, even though such nonwords do not have a lexical or semantic representation (Bentin & McCarthy, 1994; Holcomb, 1993; Nagy & Rugg, 1989; Rugg, 1984). This research implies that the N400 is independent of lexical access and not contingent on semantic relationships.

Cognitive functioning in relation to the N400 has also been proposed to reflect lexical access (Bentin, 1987; Kutas & Hillyard, 1989; Van Petten & Kutas, 1987) and post-lexical mechanisms such as contextual integration (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Chwilla, Hagoort, & Brown, 1998; Holcomb, 1993; Rugg, 1990; Rugg & Doyle, 1992; St. George, Mannes, & Hoffman, 1994) and expectancy-induced priming (Holcomb, 1988). Halgren (as cited in Scheibel & Wechsler, 1990) suggested that lexical access and contextual integration may not be independent. The potential semantic nature of a stimulus was said to be determined during lexical encoding. The meaning of the

encoded stimulus is then accessed and integrated into its cognitive context. N400 amplitude is thus modulated by the level of processing required to simultaneously access meaning (lexical access) and integrate the stimulus (contextual integration). Therefore, it was proposed that lexical access and contextual integration could be part of a single process.

The automaticity of the processes underlying the N400 have been investigated in order to determine the validity of the lexical and post-lexical hypotheses presented above. ERP experiments have manipulated the proportion of related stimuli (Chwilla, Brown, & Hagoort, 1991; Holcomb, 1988), the SOA (Boddy, 1986), task relevance (Bentin, Kutas, & Hillyard, 1993; Mitchell, Andrews, Fox, Catts, Ward, & McConaghy, 1991) and selective attention (Kellenbach & Michie, 1996; McCarthy & Nobre, 1993). This has provided a means of determining whether the N400 and reaction time measures reflect automatic processes associated with spreading activation and lexical access, or attentional processes associated with post-lexical mechanisms such as expectancy or stimulus integration.

SOA is the time between the onset of one stimulus and the next, and this time interval has been manipulated to alter the level of automatic and attentional processing. ERPs to stimuli with short SOAs are assumed to reflect automatic processing, as the paradigm does not allow enough time to commit attentional resources. Boddy (1986) recorded ERPs in a lexical-decision task in which primes preceded nonwords, related words and unrelated words. The relationship between these word pairs was studied across SOAs ranging from 200 ms to 1000 ms. A priming effect on N400 amplitude was elicited for all the SOAs in the above range. The priming effect thus cannot be accounted for solely

using the ASA mechanism because the priming effect occurred at long SOAs. The lexical access expectancy mechanism requires an attentional shift, and therefore is unable to account for the priming effect at short SOAs. However, Hodgson (1991) reported semantic-priming effects at short and long SOAs and suggested that matching or integration mechanisms can also occur at short SOAs.

Research manipulating the focus of attention on the semantic relationship between stimuli has demonstrated that the N400 is sensitive to the level of attention demanded by the task. The priming effect on N400 amplitude has been reported to be largest when semantic processing is task relevant and therefore reflects some aspects of an active attentional mechanism. However, this result has been interpreted as implying that the N400 also reflects some aspect of automatic processing associated with lexical access (Kutas & Hillyard, 1989).

Chwilla, Brown and Hagoort (1991) used a lexical decision task (LDT) and a silent reading task comprising high (0.8) and low (0.2) proportions of semantically-related stimuli. Word targets were preceded by semantically-related, unrelated or neutral primes. A priming effect on N400 was reported for both tasks and was largest in the high proportion condition. It was concluded that the N400 is influenced by attentional processing, because a truly automatic process would not be affected by changing the level of processing. The sensitivity of the N400 to the manipulation of relatedness proportion suggests that it may be a correlate of the expectancy mechanism.

Bentin et al. (1993) studied the N400 priming effect in terms of attention to the semantic relationship between stimuli in the auditory modality. The attend condition consisted of a

recognition memory task in which subjects were required to memorize the words in order to perform a subsequent recognition task. The words presented were either related or unrelated to the preceding word. The unattended condition was a LDT in which subjects counted pseudowords. They found a significant N400 priming effect only in the recognition memory task. The distribution of the N400 was described as equipotential over the scalp. The results suggested that the recognition memory task involved more semantic processing than the counting of pseudowords in the LDT, and it was concluded that the degree of semantic analysis is important in determining the extent of the N400 effect.

Similarly, Sanquist et al. (1980) varied attention by instructing subjects to determine whether two words were the same or different based on semantic, orthographic and phonemic criteria. A significant N400 effect was found only when subjects determined that the two words were different using the semantic criteria. Since a priming effect on N400 was not obtained in the orthographic or phonemic conditions, it can be assumed that the N400 reflects controlled processing and its amplitude is modulated by the degree of semantic analysis.

Brown and Hagoort (1993) varied attention using a masking paradigm. Visual masked priming involves presenting a pattern mask (e.g. hash marks, skewed letters) immediately following the presentation of a prime word. Following the prime word, an unmasked target word is presented on which a particular task is to be performed (for example, lexical decision). The masking technique was used under the assumption that it prevents a stimulus from reaching conscious perception. A priming effect on N400 was elicited only in the unmasked condition. However, a reaction time priming effect was found in both

masked and unmasked conditions. The dissociation between reaction time and N400 was taken to indicate that reaction time was associated with both automatic and controlled aspects of semantic-priming, whilst the N400 reflected only the controlled component. Since masking is assumed to eliminate perceptual identification, it was concluded that the N400 effect cannot be associated with lexical access and therefore reflects conscious attentional processing associated with lexical integration.

Holcomb (1993) altered the level of attention using target degradation, which was assumed to affect lexical processes. Subjects were required to perform a LDT to words and pseudowords preceded by either semantically-related or unrelated prime words. In the first experiment targets were degraded by removing 33 % of elements forming each letter. In the second experiment targets were degraded by overlaying them with a matrix of dots. There was no difference in the priming effect on N400 between targets that were degraded and those that were not, but reaction time was found to be longer in response to degraded targets. A dissociation existed between reaction time and N400, implying that these measures do not necessarily reflect the same set of cognitive operations. Because priming effects on reaction time were affected by degradation, it was concluded that reaction time reflects automatic lexical processing. Since the priming effect on N400 was not influenced by the disruption to lexical processes due to degradation, it was concluded that the N400 is sensitive to post-lexical integrative processes. They suggested that the N400 priming effect reflects the ease with which integrative processes can incorporate word-level information into the current discourse - the more difficult the integration, the larger the N400 amplitude.

Chwilla, Hagoort and Brown (1998) provided further support for a semantic

matching/integration account of the N400 priming effect using a backward-priming paradigm in a lexical decision task. Backward priming is described as facilitation emerging due to an association from the target to a preceding prime when there is no association from the prime to the target. An N400 backward-priming effect was reported and shown to reflect the post-lexical semantic matching/integration mechanism. Since the results were obtained at both short and long interstimulus intervals, it was suggested that the subjects were able to rapidly integrate the semantic and syntactic lexical information relating to the target with that provided by the prime. They concluded that the semantic matching/integration mechanism may reflect a fast-acting mandatory process. This is contrary to the view that integration occurs only at long intervals (Neely & Keefe, as cited in Bower, 1989).

The extent of attentional processing has also been manipulated using selective attention paradigms. Such paradigms are used to investigate whether controlled or automatic processing occurs by varying the extent to which stimuli are processed. Stimuli undergo controlled processing when they enter into consciousness as a result of attentional focus. Selective attention paradigms have also provided evidence that the N400 reflects post-lexical processes. McCathy and Nobre (1993) used a spatial selection paradigm, presenting lists of words containing semantically-related items. Subjects were required to select words in a specific spatial location which were associated with a nominated semantic category, while ignoring such words in another location. A priming effect on N400 was elicited only by words in the attended location. Similar findings have been established in the auditory modality. Bentin, Kutas and Hillyard (1995) used a dichotic listening task to assess the effects of selective attention on the N400 priming effect. Semantically-related and unrelated word pairs were presented to both ears, and subjects

were instructed to memorize the words presented in one ear while ignoring those presented in the other. An N400 priming effect was only obtained to words presented in the attended channel. Kellenback and Michie (1996) used a paradigm combining lexical decision and colour-cued selective attention. Subjects were required to select stimuli based on colour, and perform a LDT on the attended items. An N400 priming effect was elicited only when the prime was the focus of attention. Such effects were found to be independent of the attentional status of the target. It was concluded that N400 amplitude is modulated by the ease with which an item is integrated into an attended prior context.

No definite conclusions can be drawn regarding the processing nature of the N400. It has been associated with automatic lexical processing and controlled post-lexical processing, but the literature favours the latter. However, it would appear that the priming effect on N400 amplitude is influenced by the extent of contextual processing.

4.1.1.3. TOPOGRAPHY

There is some discrepancy in the topography of the N400 in various paradigms. However, most of the paradigms using linguistic stimuli in word or sentence contexts report an N400 effect between 250 ms and 600 ms which is maximal in the centro-parietal region of the right hemisphere (Curran, Tucker, Kutas, & Posner, 1993; Kutas & Hillyard, 1983; McCarthy & Nobre, 1993). However, Boddy (1986) used a lexical decision task and found a more fronto-central N400 effect, which was greater over the left hemisphere. Similarly, Stuss et al. (1983, 1986, 1992) reported frontal negativity in the N400 latency range elicited by isolated words in picture-naming and completion tasks.

The topographic and latency variability of the N400 in various paradigms is often

attributed to overlapping ERP components. Kutas et al. (1988) found that varying the presentation rate of words in a silent reading task altered topography. When the stimulus onset asynchrony was 200 ms or less, the N400 effect was greater frontally than with slower rates of presentation. It was concluded that this was the result of an overlapping decision- or response-related positive component (P3).

Paradigms using nonverbal stimuli have also reported a more frontally-distributed N400 (Barrett & Rugg, 1989, 1990; Barrett, Rugg, & Perret, 1988; Polich, Vanasse, & Donchin, 1980; Stelmack & Miles, 1990). However, Nigam et al. (1992) recorded a centro-parietal N400 to incongruous pictures used to terminate sentences. The distribution and latency of the N400 elicited was the same as that for terminal words. Although the stimuli used in this task were nonlinguistic, they were presented in a sentential context, making them meaningful and easily interpreted in the same manner as terminal words.

Kutas, Hillyard and Gazzaniga (1988) studied the relative differences of semantic information processing in the left and right hemispheres. The experiment was based on the premise that elicitation of the N400 requires acknowledgment of semantic contexts and realisation that a word is inappropriate in a given context. Subjects consisted of five commissurotomized individuals who were presented with words that were semantically appropriate and inappropriate to the sentence context. These sentence fragments were presented aurally but the endings were flashed to the left or right visual field and ERPs were recorded to these word endings. At the end of each sentence the subject's judgement regarding the congruity of the terminal word was established by pointing to one card or another containing the words 'sense' and 'nonsense'. It was found that all the subjects could perform this task at greater than chance accuracy. In a second task, patients listened

to sentence fragments completed by two words flashed simultaneously to the right and left visual fields while ERPs were recorded. Priming was assessed by comparing the ERPs elicited by semantic anomalies relative to congruous endings. It was found that all five patients showed N400s to the semantic anomalies flashed to the left hemisphere but only two showed this when the anomalies were flashed to the right hemisphere. These two patients differed from the others in being able to control speech via the right hemisphere. It was hypothesised that different brain organisations may be subserving semantic processing. One is associated with semantic priming and is related to speech control, and the other does not underlie priming but can be used to comprehend language. They suggested that the data implied a dissociation between the semantic processes that lead to N400 generation and those used to make semantically-based judgements.

4.2. OTHER EVENT-RELATED POTENTIALS

4.2.1 THE RELATIONSHIP BETWEEN N400 AND N2

There has been considerable controversy regarding the relationship between the N400 and N2 ERP components. Despite the robustness and functional specificity of the N400, several researchers have attempted to show that the N400 effect may be due to subtle shifts in timing or morphology of other components, which have been linked to violations of expectancy outside the linguistic domain.

The N400 has been interpreted as a delayed N2, a component commonly associated with violations of expectancy (other than linguistic) with a mid-anterior topography (Ritter, Ford, Gaillard, Harter, Kutas, Näätanen, Polich, Renault, & Rohrbaugh, as cited in Karrer, Cohen, & Tueting, 1984; Ritter, Simon, & Vaughan, 1983; Polich, 1985). Polich (1985) reported that when subjects were required to perform a semantic categorisation task, N400

was followed by a P3 similar to that following the N2. The results also revealed a relationship between reaction time and P3 latency. It was concluded that task difficulty was positively related to P3 latency, which extended the latency range of the N2 component to that associated with the N400.

Ritter et al. (1983) supported the latter conclusion, suggesting that the N2 reflected stimulus classification and was elicited regardless of the type of stimulus to be classified. The latency of the N2 was assumed to be related to the time required for stimulus evaluation. Since semantic evaluation is assumed to be more complex than physical discrimination, the duration of evaluation is longer, resulting in a delayed N2 component.

However, the N400 has a more centro-parietal distribution compared with the frontal distribution commonly associated with the N2. The difference in scalp topography makes it difficult to suggest that they emerge from the same neural source, although Deacon, Breton, Ritter, Herbert and Vaughan (1991) reported that the N2 and N400 were similar in topography. The two components also differ in terms of the ease with which their latency is manipulated. Näätanen and Galillard (as cited in Gaillard & Ritter, 1983) reported that reaction time and the latency of the N2 component were increased when the physical characteristics of rare and frequent stimuli were made more similar. However, such effects have not been observed with the N400. In a comparable experiment, Kutas and Hillyard (1984) reported that N400 latency was not sensitive to changes in cloze probability, although there were no reaction time measures. These represent attempts to dissociate the N2 and N400 based on function by showing differences using cognitive manipulation. In an experiment by Connolly and Phillips (1994) the phonological mismatch negativity (PMN) or N2 and N400 were shown

to co-occur to terminal words in sentences presented in the auditory modality. This only occurred when the terminal word was completely semantically anomalous, that is, the initial phoneme was totally unexpected in relation to the context established by the sentence. Hence it is unlikely that the N2 and N400 are the same component. Despite the controversy, it is now commonly accepted that the N400 is a distinct component.

4.2.2. P3

The P3 component has been described as a late positive ERP component, elicited in response to task-relevant stimuli (Duncan-Johnson & Donchin, 1977; Sutton, Braren, John, & Zubin, 1965). However, the 'classical P3' has been associated with a wide variety of tasks, and reported latencies range from 300 to 900 ms, resulting in researchers assigning numerous labels. The various P3s are often thought to reflect different cognitive processes. The scalp topography for these positive peaks appears to be consistently centro-parietal (Donchin, McCarthy, Kutas, & Ritter, 1983).

The 'oddball' paradigm is one which has consistently been shown to elicit the classical P3. The paradigm requires subjects to determine whether a stimulus is consistent with one of two categories presented in a random sequence. The categories are presented with different probabilities, to form frequent and rare categories. It has been reported that a parietally-distributed P3 is elicited, with the amplitude inversely related to the probability of the category (Ford, Roth, & Kopell, 1976; Squires, Donchin, Herning, & McCarthy, 1977; Squires, Donchin, Squires, & Grossberg, 1977). However, Gonsalvez, Gordon, Grayson, Barry, Lazzaro and Bahramali (1999) showed that decrements in target-probability prolong the target-to-target interval, and suggested that this temporal variable

may be the more-basic underlying characteristic of the stimulus sequence which enhances P3 amplitude.

The P3 has also been identified in language and memory tasks (Friedman, Vaughan, & Erlenmeyer-Kimling, 1981). The component has been elicited in a variety of paradigms and has been subjected to various interpretations. Variations in the amplitude of the P3 have been interpreted as reflecting elaborative processes (Neville, Kutas, Chesney, & Schmidt, 1986), context updating (Donchin, 1981) and contextual closure (Friedman, Simson, Ritter, & Rapin, 1975). The following paragraphs will consider the P3 in relation to semantic evaluation of stimuli in different paradigms.

In an experiment by Friedman et al. (1975) sentences were sequentially presented to subjects and it was reported that the P3 was enhanced to the terminal word of the sentences. The enhanced P3 was interpreted as reflecting ‘syntactic closure’. Kutas and Hillyard (1980a) replicated and extended the experiment, and reported that an ERP complex consisting of an N400 and P3 was elicited when the terminal word was semantically incongruous and surprisingly large font size in relation to presentation size. Similar studies have since reported a consistent component overlap between the N400 and a centro-parietal P3. The occurrence of a P3 may impact on the N400 amplitude and latency, making interpretation of priming effects difficult (Kutas & Hillyard, 1982; 1983; Mitchell, Andrews, Fox, Catts, Ward, & McConaghy, 1991; Van Petten & Kutas, 1991a,b; Woodward, Ford, & Hammett, 1993). The underlying cognitive processing reflected by the P3 has been interpreted in different ways, including integrative elaborative processing (Andrews et al., 1983), and syntactic closure (Kutas & Hillyard, 1982, 1983; Van Petten & Kutas, 1991b), while Roth and Boddy (1989) suggested it may

reflect some other, undefined, aspect of sentence completion.

An ERP experiment conducted by Polich (1985) investigated the N400 and P3 by varying task demands in a sentence and semantic categorization task. Subjects were required to either read the stimuli presented or make a button-press judgement regarding the congruity of the final word. The reading task elicited a fronto-central N400-like effect for both paradigms without eliciting a robust P3 component. However, in the judgement task, the N400 effect preceded a clear P3. This illustrated the sensitivity of the P3 to task demands. The task requiring an active decision elicited a P3, which could be associated with closure, or resolution of uncertainty. The findings of Polich (1985) are supported by judgement tasks involving verbal stimuli that have elicited an N400 effect followed by late positivity (Bentin et al., 1985; Boddy & Weinberg, 1981; Curran, Tucker, Kutas, Posner, 1993; Polich, Vanasse, & Donchin, 1980; Sanquist et al., 1980). Such support has also been established in categorization and matching tasks (Harbin, Marsh, & Harvey, 1984; Noldy, Stelmack, & Campbell, 1990; Rugg, 1984, 1985).

4.2.2. THE RELATIONSHIP BETWEEN N400 AND P3

It is difficult to determine whether the N400 reflects cognitive activity that is independent of the P3. Studies have often reported an N400 effect superimposed upon a centro-parietal P3 effect (Bentin et al., 1985; Boddy, 1986; Holcomb, 1986). Curran, Tucker, Kutas and Posner (1993) studied the distribution of the N400 over time to semantic anomalies at the end of sentences. The congruous condition displayed an N400 followed by P3 with a centro-parietal distribution and latency range of 360 ms to 600 ms. The P3 was not evident in the incongruous condition over the same latency range - instead, it commenced at approximately 580 ms. It was concluded that the delay in the latency of the P3 in the incongruous condition may reflect additional time required to resolve the

semantics of the anomalous word given the preceding context. It was proposed that the priming effect on N400 amplitude could be accounted for by the latency-shift of the P3. Also, Dien (1998a) used principal components analysis (PCA) and showed that almost all the variance due to congruousness was accounted for by a P3 factor, whilst failing to identify a distinct N400 factor.

However, the N400 component can be distinguished from the P3 if experimental conditions vary N400 latency and amplitude independently of P3. Kutas and Hillyard (1980c) compared a physical violation with a semantic violation at the terminal positions of sentences and showed that P3 was enhanced when the deviation was of a physical nature (increase in the size of print) whereas semantic deviation (incongruous terminal word of sentences) resulted in a larger N400 than semantically-congruous endings. It should also be noted that the P3 is usually absent or reduced following the N400 in tasks that do not require an overt response (Fischler, Childers, Achariyapaopan, & Perry, 1985), and to mid-sentence words (Kutas & Hillyard, 1983). Rugg (1985) performed a lexical decision task manipulating the proportion of targets preceded by identical and related primes. A priming effect on N400 amplitude occurred without any subsequent differences in P3 amplitude or latency. This indicated that the priming effect on N400 amplitude could not be attributed to variations in P3 amplitude and latency. Other studies have also reported similar results (Bentin, McCarthy, & Wood, 1985; Fischler et al., 1983).

Kutas and Hillyard (1983) demonstrated that the N400 can occur in the absence of the P3 component. ERPs were recorded to congruous and incongruous words at intermediate and terminal positions in sentences. Words occurring at intermediate positions elicited an N400 in the absence of the P3, whereas terminal words elicited an N400 effect that

overlapped with a P3 component. These findings have been confirmed in similar studies (Kutas, Van Petten, & Besson, 1988; Neville et al, 1986; Polich, 1985).

Overall, the literature suggests that tasks which elicit a P3 may impact on the N400 amplitude and latency, making interpretation of priming effects difficult. However, this has been overcome in some studies and the N400 effects have been shown to occur independently of the P3 effects. Tasks that elicit the N400 in the absence of a P3 show a clear dissociation between the two components, indicating that the N400 effect cannot be explained by changes in P3 latency alone (Deacon, Hewitt, & Tamny, 1998).

The P3 has been associated with rare/unexpected events, and it is possible that a general mechanism may be used to detect semantic deviations rather than a specific mechanism reflected in the N400. However, the research reviewed in earlier sections referring to fMRI, PET and ERPs suggests that some cognitive processes are functionally and anatomically distinct, implying that the detection of semantic deviations may involve a specific mechanism. Ambiguities still exist in this field due to the spatial and temporal overlap of the ERP components. This thesis aims to explore the extraction of meaning in the reading process using information derived from the ERP. To this end it addresses the issue of component identification and separation as well as component processing using data analysis techniques (principal components analysis and difference waves) and experimental design techniques. Specifically, the issue of component overlap between the N400 and P3 was addressed using these techniques. In addition to these two components, the role played by other ERP components (relatively overlooked in this literature to date), and the possible cognitive processes they reflect, was explored. Ultimately, the data so generated were integrated into a preliminary (and rather tentative) ERP-based model of word processing.

CHAPTER 5

EXPERIMENT 1

5.1. INTRODUCTION

It has been established that the processes of language comprehension are influenced by linguistic context. This is especially apparent in the single-word semantic-priming paradigm, in which processing of a target word is facilitated when it is preceded by a semantically-related or -associated context provided by the prime word (Becker, 1979; DeGroot, 1985; DeGroot, Thomassen, & Hudson, 1982; Meyer & Schvaneveldt, 1971; Neely, 1976, 1977). For example, in a relatedness-judgement task, the word "milk" is responded to faster when preceded by a semantically-related word such as "cow" than when it is preceded by an unrelated word such as "apple". The mechanisms proposed to underlie word recognition and semantic priming may be distinguished in terms of whether they are mediated by automatic or controlled processes. Automatic processes are considered to be fast-acting, and once commenced cannot be prevented, are not influenced by strategy, do not require conscious attention or awareness, and do not require (or impact minimally on) limited attentional capacity. Controlled processing is described as slow-acting, involves strategy, and requires conscious attention (Posner & Snyder, as cited in Solso, 1975; Schneider, Dumais, & Shiffrin, as cited in Parasuraman & Davies, 1984; Shiffrin & Schneider, 1977).

Word recognition models distinguish between the processes of lexical access and lexical integration. An established mental lexicon is assumed to be composed of word-form and word-meaning representations, which are organised in a systematic way in relation to

associative and semantic relationships (Chwilla, Hagoort, & Brown, 1998). Lexical access is described as an automatic process that involves activating the mental lexicon and the subset of lexical elements, including the semantic and syntactic attributes of those elements. Integration is considered to be a controlled process involved in integrating the lexical elements into a higher order meaning representation of the entire discourse.

Neely and Keefe (as cited in Bower, 1989) proposed a three-process model of semantic memory to account for priming, incorporating spreading activation, expectancy-induced priming and semantic matching/integration. At the lexical-access level, there are the automatic spreading activation (ASA; Collins & Loftus, 1975; Neely, 1977) and expectancy-induced priming mechanisms (Becker, 1985; Posner & Snyder, as cited in Solso, 1975). ASA is assumed to be a purely-automatic process which occurs as a result of lexical access. Expectancy generates a set of related target words based on the information from the prime. This form of priming is influenced by strategy and requires sufficient time to generate the expectancy set, and therefore is considered to be a controlled process. However, De Groot (1984, 1985) reported a relatedness-proportion effect in a lexical decision task with a short stimulus onset asynchrony (SOA). It was concluded that the post-lexical meaning integration process could be fast-acting, suggesting that it is a mandatory process utilized for comprehension (Fodor, 1983). Semantic matching involves processing associated with post-lexical integration, that is, integration of a lexical element into a context to form a "higher-order meaning representation of the entire discourse" (Brown & Hagoort, 1993, p. 34).

Task-related manipulations have been shown to influence semantic priming, with the manner in which attention is directed by the task influencing the size of the semantic-

priming effect. For example, tasks directing attention to the letter level or physical structure, or requiring counting, produce smaller semantic-priming effects than tasks directing attention to the semantic attributes of the words, particularly the prime (Bentin, Kutas & Hillyard, 1993; Friedrich, Henik, & Tzelgov, 1991; Henik, Friedrich, & Kellog, 1983; Henik, Friedrich, Tzelgov, & Tramer, 1994; Kaye & Brown, 1985; Silva-Pereyra, Harmony, Villanueva, Fernandez, Rodriguez, Galan, Diaz-Comas, Bernal, Fernandez-Bouzas, Marosi, & Reyes, 1999; Smith, 1979; Smith, Theodor, & Franklin, 1983; Stoltz & Besner, 1996).

In terms of electrophysiological measures, amplitude modulation of a negative ERP component with a centro-parietal topography and a peak latency at approximately 400 ms postimulus (N400) is regarded as an index of semantic priming. It has been established in a variety of tasks that the amplitude of the N400 is attenuated when a target word is semantically or associatively related to its preceding context (Bentin, McCarthy, & Wood, 1985; Kutas & Hillyard, 1980a, 1980b, 1984; Kutas & Van Petten, as cited in Ackles, Jennings, & Coles, 1988). The priming effect on N400 amplitude is thought to reflect a controlled process of post-lexical integration (Bentin, Kutas, & Hillyard, 1993; Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Chwilla, Hagoort, & Brown, 1998; Kellenbach & Michie, 1996).

This perspective has emerged from studies that have influenced the priming effect on N400 amplitude by manipulating the extent of semantic analysis. For example, Chwilla et al. (1995) required subjects to perform either a lexical-decision task, or a physical discrimination task in which they determined whether the target word was in upper or lower case. The N400 priming effect occurred only in the lexical-decision task.

Similarly, Bentin, Kutas and Hillyard (1993) investigated the influence of task on ERPs in the auditory modality. The experiment consisted of two tasks, in one of which subjects listened to a list of words in anticipation of a recognition-memory test, while in the other, subjects silently counted pseudowords. A priming effect on N400 amplitude was only reliable for the recognition-memory task. It was concluded that the size of the priming effect on N400 amplitude was influenced by the extent that task demands required attention to semantic analysis.

This conclusion was also supported by Chwilla, Brown, and Hagoort (1991), who investigated semantic priming using a silent-reading and lexical-decision task consisting of word pair presentations with high (0.8) and low (0.2) proportions of related versus unrelated pairs. A priming effect on N400 occurred in both tasks but was enhanced in the condition with the high proportion of related pairs. High relatedness proportions are assumed to induce strategic attentional processing involving semantic analysis, suggesting that the N400 reflects aspects of controlled attentional processing.

This conclusion is also consistent when comparing tasks between experiments. For example, Kutas and Van Petten (as cited in Ackles, Jennings, & Coles, 1988) recorded ERPs in a task requiring subjects to determine the extent to which word pairs were semantically associated. Essentially the same stimuli were used by Kutas and Hillyard (1989) in a delayed letter-search task requiring subjects to determine whether a letter displayed 1.2 seconds after the target word was part of either or both of the words. An N400 effect was found in both experiments but was considerably larger when the semantic relationship between word pairs was explicitly attended in the ratings task. In the Kutas and Hillyard (1989) experiment it was concluded that the priming effect on

N400 reflects lexical access because the task did not require semantic processing. However, there was no objective measure of the extent of semantic processing, so the controlled process of lexical integration cannot be ruled out completely.

Further evidence that the N400 priming effect reflects post-lexical processing comes from studies addressing the effects of selective attention (Hillyard & Kutas, 1995; Kellenbach & Michie, 1996; McCarthy & Nobre, 1993). These studies have shown that priming influences the amplitude of the N400 when at least the prime is in the focus of attention and is processed for meaning.

However, it should be noted that Schnyer, Allen, and Forster (1997) reported a significant N400 effect with masked repetition priming. Words were flashed for 48 (ms) and then repeated after a word that acted as the masking stimulus. These words showed an attenuation in N400 amplitude. It was concluded that the early (N400) ERP repetition effect may be automatic and reflect implicit memory processing. This challenges the conceptions of the N400 as reflecting conscious processing. This is supported by others who have reported significant priming in N400 amplitude using single-word priming paradigms with a stimulus onset asynchrony considered to be too short to allow post-lexical processes to occur. (Anderson & Holcomb, 1995; Deacon, Hewitt, & Tamny, 1998).

Regardless of this, the majority of the literature maintains that the target N400 priming effect reflects post-lexical integration (Besson, & Kutas, 1993; Rugg, Doyle, & Holdstock 1994).

Semantic priming can be interpreted in the interactive activation (IA) framework of visual word recognition described by Stolz and Besner (1996). In the model there are two ways in which semantic-priming effects can emerge. Firstly, word recognition of the prime would be considered to result from initially activating letter-level representations; activation then flows on in an excitatory fashion to the word level. Activation of the most consistent word candidates is assumed to result from within-level competitiveness. Similarly, the word level activates consistent information at the semantic level, including semantic associates. Subsequent presentation of the target stimulus requires less bottom-up activation for recognition. Semantic priming is the result of between-level spreading activation of associates. Thus far, information has been fed bottom-up from the letter level to the semantic level.

The bi-directional nature of information processing between levels means that top-down processing can provide support for activation flowing bottom-up, but only in an excitatory fashion. The second manner in which semantic priming effects can emerge is when semantic associates activated through bottom-up processing result in the activation of word-level representations for the prime and the semantic associates via top-down processing. Within-level competitiveness ensures that activation for the prime word remains higher than that of the associates. Subsequent presentation of the target requires less activation for recognition relative to unprimed targets.

In the experiments by Stoltz and Besner (1986) the prime task was letter search and the target task was lexical decision. In one condition, a probe letter was presented simultaneously in upper case above each letter of the prime word. Subjects decided whether the probe letter matched a letter in the prime. This task was followed by a lexical

decision based on the target. The second condition was the same as the first except the prime was previewed alone for 200 ms prior to the simultaneous presentation of the prime and probe letter. Letter search of the prime when the probe letter appeared simultaneously yielded the traditional elimination of semantic priming in the lexical-decision task, but when the probe letter was delayed, a significant priming effect was obtained in the lexical-decision task. It should be noted that the prime was exposed for an additional 200 ms when the probe letter was delayed and this alone may account for the different findings between the two tasks. In a second experiment, these two conditions were intermixed and significant priming in the lexical-decision task was reported for both conditions.

It was suggested that the flow of information between levels can be altered by 'between-level blocking' and this was discussed in relation to the interactive activation framework. When the prime and probe were presented simultaneously, the letter level activated the word level but activation was said to be blocked between the word level and the semantic level. Hence, semantic associates of the prime were not activated, eliminating semantic priming. In contrast, the preview condition allowed activation to flow between the word and semantic levels, activating prime associates and enabling priming to occur. This suggested that blocking was not an automatic result of letter search. When the simultaneous probe and delayed probe conditions were randomly intermixed and semantic priming occurred for both conditions, it was concluded that presentation of a word does not necessarily result in activation at the semantic level. It was suggested that activation and blocking may result from the experimental context biasing focal attention to different levels of the model.

As noted earlier, the priming effect on N400 amplitude elicited by the target is enhanced

by tasks encouraging semantic analysis, and this is assumed to reflect post-lexical integration processes. However it seems unusual that the delayed letter search task reported by Kutas and Hillyard (1989) resulted in a priming effect on N400 amplitude when the task was assumed to be non-semantic. The aim of their experiment was to determine whether a priming effect on N400 amplitude would be elicited in target responses when the semantic relationship between the prime and target was not task relevant. It was also designed to address the issue of whether the N400 is an index of semantic association, independent of an overlapping P3 effect reported in earlier lexical-decision and category-judgement tasks (Bentin et al., 1985; Holcomb, 1986). In such tasks it was difficult to determine whether the variation in N400 amplitude was independent of the amplitude and latency variations of P3. In order to accomplish this Kutas and Hillyard (1989) used a letter search comprised of related and unrelated word pairs, followed by a letter probe delayed to 1200 ms post target onset. It was assumed that letter search does not involve the use of semantic properties and that the delayed decision avoided any overlap between the "ERP indices of semantic association (N400) and the more general decision related responses (P3)" (Kutas & Hillyard, 1989, p. 39). In this way, it was expected that any effect on N400 amplitude could be observed unconfounded by the overlapping decision-related positivity. Subjects were instructed to read the word pairs in order to allow determination of whether the letter probe had appeared in either or both of the proceeding words. Kutas and Hillyard (1989) reported that the target responses showed a priming effect on N400 amplitude independently of P3.

Semantic priming has been reported to be eliminated in a target lexical-decision task when the prime task was letter search. In those experiments the probe letter appeared simultaneously with the prime and the decision was made prior to target presentation

(Friedrich et al., 1991; Henik et al., 1983, 1984; Smith et al., 1983; Stoltz & Besner, 1996).

As described earlier, Stoltz and Besner (1996) replicated the traditional finding that semantic priming is eliminated in the target lexical-decision task when the prime task is letter search and the probe letter simultaneously appears above the prime. However, they showed that a priming effect could be achieved when the target task was lexical decision if the letter probe was preceded by the prime. In a second experiment the stimuli associated with the simultaneous and delayed probe conditions were intermixed. A priming effect was reported for the target lexical decision task in both conditions, suggesting that letter search on its own cannot account for the elimination of semantic priming.

The experiment by Johannes, Besson, Jacobs, Nazir and Carr (1997) used a delayed letter-search task, presenting the stimulus first, followed by the letter. The stimuli consisted of words, pseudowords and nonwords. The ERPs to nonwords were more positive over the entire scalp than those to words and pseudowords, which did not differ. Interestingly, words and pseudowords generated an N400 of similar magnitude whereas the nonwords did not elicit an N400. It was suggested that the N400 elicited by single words represents the process of lexical access, which can occur only partially for pseudowords. Pseudowords and words were differentiated in a further experiment using a semantic-categorization task. The task required subjects to determine whether the stimulus belonged to the semantic category defined by the prime. They reported that the N400 elicited by pseudowords was more negative than that elicited by words. It was concluded that the difference between the stimulus types (word, pseudoword and nonword) is

strongly dependent on the processing required to perform the task. ERPs associated with the task focussing on lexico-semantic processing differed from those associated with the task focussing on orthographic and letter content. Johannes et al. (1997) suggested that the language system is highly flexible and adaptive in the sense that "if optimal task performance can benefit from multiple sources of linguistic information, there is no doubt that this information will be activated and used" (p. 770).

As described earlier, the priming effect on N400 amplitude elicited by the target is enhanced by tasks encouraging semantic analysis, and this has been suggested to reflect post-lexical integration processes. Kutas and Hillyard (1989) claimed that the letter-search task adopted in their experiment was a non-semantic task, hence unlikely to elicit a priming effect. Overall, it is surprising that the delayed letter-search task conducted by Kutas and Hillyard (1989) resulted in a priming effect on N400 amplitude. Contrary to the current literature, it was concluded that the N400 reflected processing associated with an automatic component of semantic priming. The aim of the current experiment was to replicate this finding, given that it seems contrary to the growing body of literature.

5.2. METHOD

5.2.1. SUBJECTS

Nineteen university students (16 females and 3 males) aged between 19 and 31 years (mean = 20.8 yrs) participated in the experiment as one means of satisfying a course requirement. All subjects spoke English as their first language and had normal or corrected-to-normal vision.

5.2.2. STIMULI AND DESIGN

Sixty semantically-associated word pairs (primes/targets) of 3-9 letters (mean = 5.4 letters) were selected from Postman and Keppel's (1970) word-association norms of production. The pairs selected were either first- or second-choice associates. Sixty semantically-unrelated word pairs were also generated, matching the semantically-related word-pairs on word length.

The experiment was a letter-search task (LS) comprised of sixty semantically-associated word pairs and sixty unrelated word pairs. The stimulus pairs were randomised, except that no more than three related or unrelated word pairs occurred consecutively and no prime was related to the preceding target.

The one hundred and twenty word pairs were each followed by a letter punctuated by a question mark, and were presented consecutively in a single block. Stimuli were presented foveally on a monitor, with each word exposed for 200 ms, with an inter-stimulus interval of 500 ms between the primes and targets. The punctuated letter following the targets was displayed for 200 ms after an interstimulus interval of 1200 ms. The intertrial interval was 2000 ms, during which a fixation point was presented. The viewing distance was 110 cm and the stimuli were presented in upper case letters 10 mm high and 5 mm wide.

5.2.3. ERP RECORDING

EEG activity was recorded from 11 scalp electrodes in an electrode cap. Electrode position was in accordance with the 10-20 system (Jasper, 1958) at frontal (Fz), central (Cz) and parietal (Pz) midline sites, and frontal (F3, F4), central (C3, C4), parietal (P3,

P4) and occipital (O1, O2) lateral sites, with linked earlobes used as the reference. Vertical eye movement (VEOG) was monitored through electrodes above and below the eye, and horizontal eye movement (HEOG) was monitored via a right to left canthal bipolar montage. The impedance at each electrode was less than 5 kOhm, and activity was amplified (EEG gain = 20,000; EOG gain = 5,000) with a bandpass of 0.01-35 Hz. EEG was continuously recorded at 256 Hz per channel and stored for offline analysis.

5.2.4. PROCEDURE

Experimental trials were presented in one block of one hundred and twenty word pairs. Subjects were not informed of the variation in the relationship between the word pairs as this was extraneous to their task. Subjects were instructed to press one of two laterally-positioned buttons as quickly and accurately as possible if they considered the probe letter had appeared in either or both of the words, and the other if the letter had not appeared in either word. Reaction times were considered valid only if they occurred during the inter-trial interval and correctly identified the presence or absence of the probe letter. The button assigned to the presence and absence of the probe letter was counterbalanced across subjects. Subjects were also instructed to minimize body and eye movements.

5.2.5. DATA ANALYSIS

Average ERPs for each site were computed, excluding those trials invalidated by excessive eye movement (> ±100 μV) or behavioural response errors. Principal Components Analyses (PCAs) were used to identify latency ranges for components in the ERP. Analysis 1 represents the traditional Target ERP analysis, while Analyses 2 and 3 also explored the component structures in the Prime ERP and their relationship with components in the Target ERP.

5.2.5.1. ANALYSIS 1

The ERP data obtained from four of the nineteen subjects was excluded due to excessive eye movement. The ERP data set consisted of 2 levels of relatedness x 11 electrodes x 15 subjects, forming 330 cases. To select latency ranges for component evaluation, PCA was carried out on data from 100 ms pre-target onset to 900 ms post-target onset, averaging every eight points in the data set (Coles, Gratton, Kramer, & Miller, as cited in Coles, Donchin, & Porges, 1986). PCA was performed on the covariance matrix using SPSS-X V8 with varimax rotation of factors. The method was chosen as a means of discriminating between components and establishing their latency ranges (Fabiani, Gratton, Karis, & Donchin, as cited in Acckles, Jennings, & Coles, 1987).

Mean amplitude measures were established for each component at each site using the latency ranges identified in the PCA. The ERP data were also normalized across scalp sites using the method described by McCarthy and Wood (1985). The raw data for each component for all electrodes except O1 and O2 were analysed using repeated measures factorial ANOVAs and planned contrasts. There were 3 levels of a lateral factor (left, right and midline), 3 levels of a sagittal factor (frontal, central and parietal), and 2 levels of relatedness (related, unrelated). Within the lateral factor, planned comparisons compared left with right activity, and their mean with activity at the midline. Within the sagittal factor, planned comparisons compared frontal with posterior activity, and their mean with central activity. Such planned comparisons allow optimal resolution of topographic effects, and their single degree of freedom F tests avoid the problems that may occur with non-sphericity of the variance-covariance matrix in repeated-measures designs. The only topographic effects reported are those that were significant in the raw data and remained so once normalised. All F tests had (1,14) degrees of freedom and the

significance criterion was $p < 0.05$. The behavioural data were analysed using repeated measures factorial ANOVAs and planned contrasts. There were 3 levels of a letter presence factor (not present, present in prime, present in target), and 2 levels of relatedness (related, unrelated). Within the letter-presence factor, planned comparisons compared letter presence in the prime and target, and their mean with responses when no letter was present.

5.3. RESULTS

5.3.1. BEHAVIOURAL DATA

Correct responses when the letter was present (904 ms, SD = 169 ms) were faster than when it was absent (1061 ms, SD = 178 ms) [$F = 40.54$, $p < 0.001$], and were faster when the letter was in the target (853 ms, SD = 174 ms) than when in the prime (955 ms, SD = 182 ms) [$F = 13.33$, $p < 0.01$]. Responses were faster for related (943 ms, SD = 167 ms) than unrelated word pairs (970 ms, SD = 167 ms) [$F = 5.05$, $p < 0.05$], regardless of letter presence.

5.3.2. ERPs

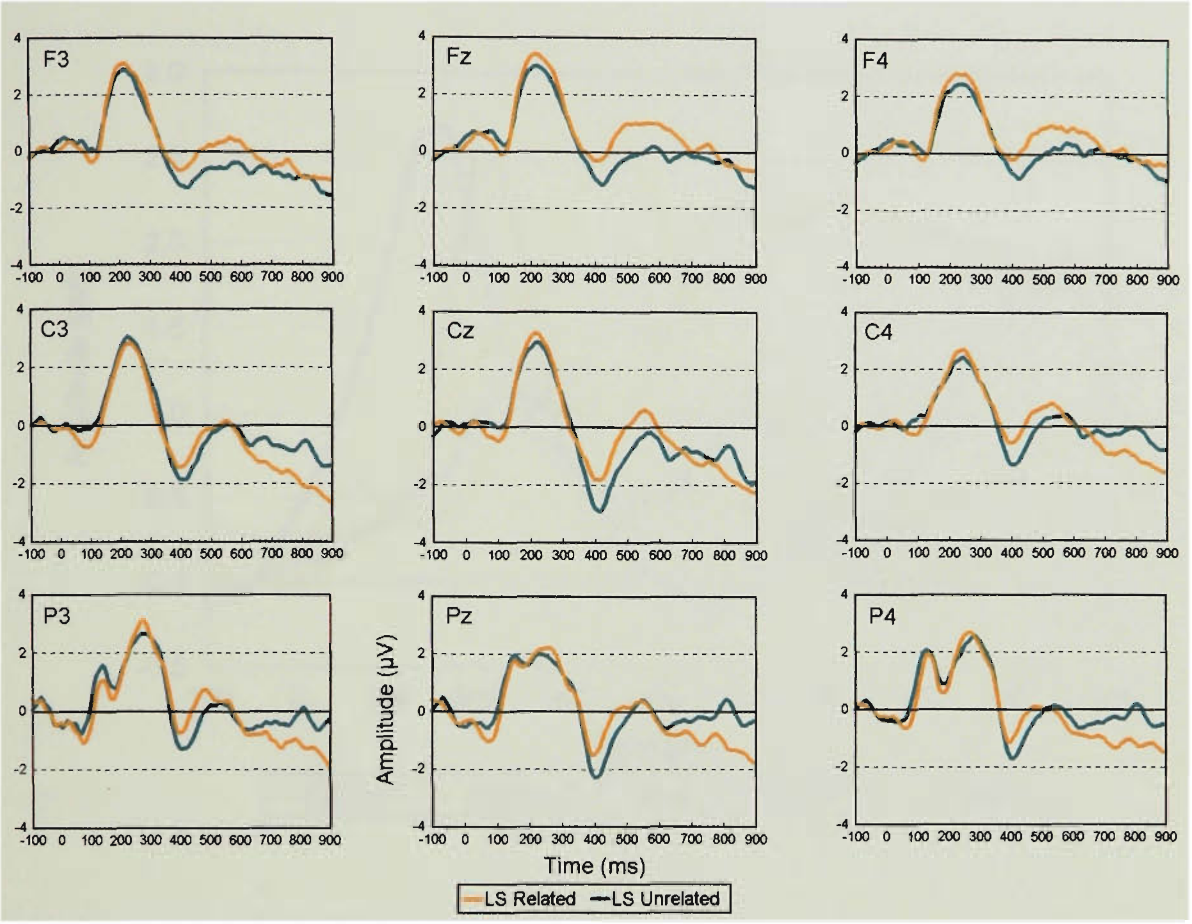


Figure 5.1. Grand average ERPs evoked by related and unrelated targets in the letter search (LS) task.

The grand average ERPs elicited by related and unrelated target responses in Figure 5.1 show a distinct positive component in the P2 latency range, which is broadly distributed over the entire scalp. In the parietal sites alone, a P1 followed by an N1 was evident, followed by the P2. A negative waveform followed the P2, peaking in the N400 latency range and displaying a central-parietal topography with some difference between related and unrelated responses. The N400 was followed by a slow wave which appeared more negative parietally for related than unrelated responses.

5.3.3. PCA

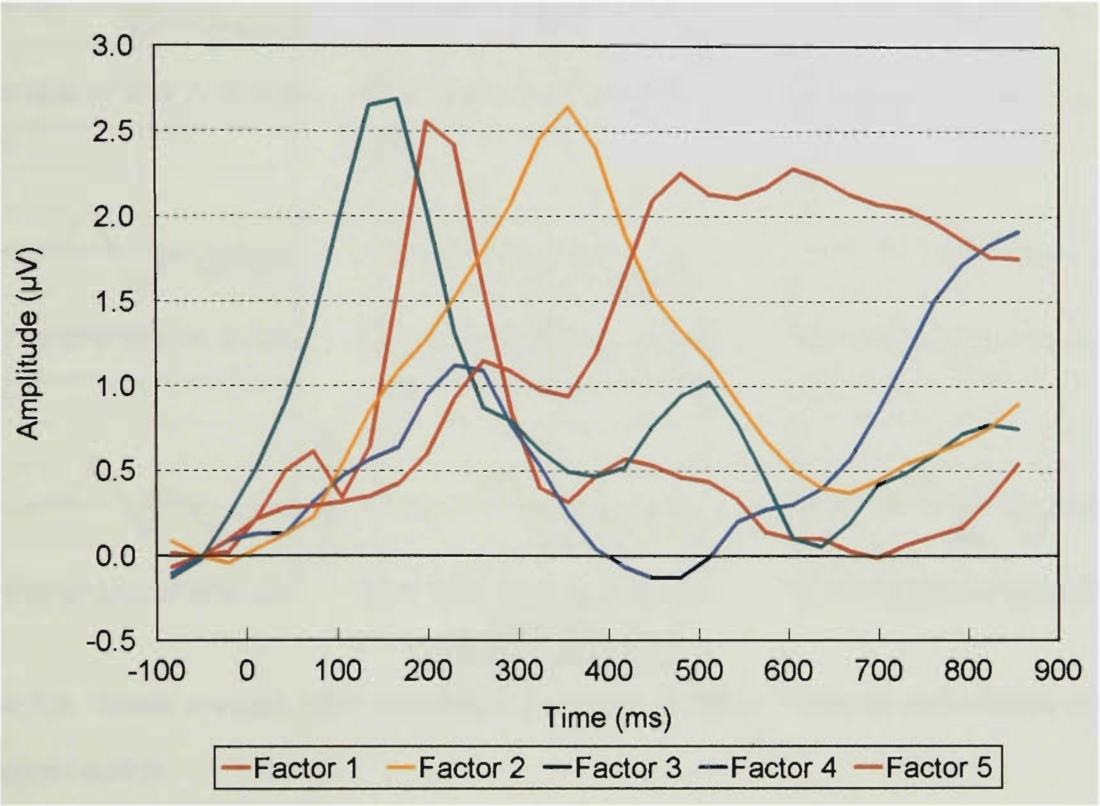


Figure 5.2. Factors extracted for target responses using principal components analysis.

The PCA produced a typical outcome in that the slowly varying component accounted for the greatest percentage of variance because it encompassed the largest region of the voltage X time function (see Figure 5.2 above). Faster components, extending over short temporal ranges, were then extracted. These components each encompassed a smaller region of the voltage by time function and therefore accounted for less of the variance. In order to identify the factors extracted using PCA, the rotated, rescaled component matrix for each factor was multiplied by the grand average ERPs to produce Figures 5.3 to 5.7 below. In these figures, the latency range associated with the component is shaded.

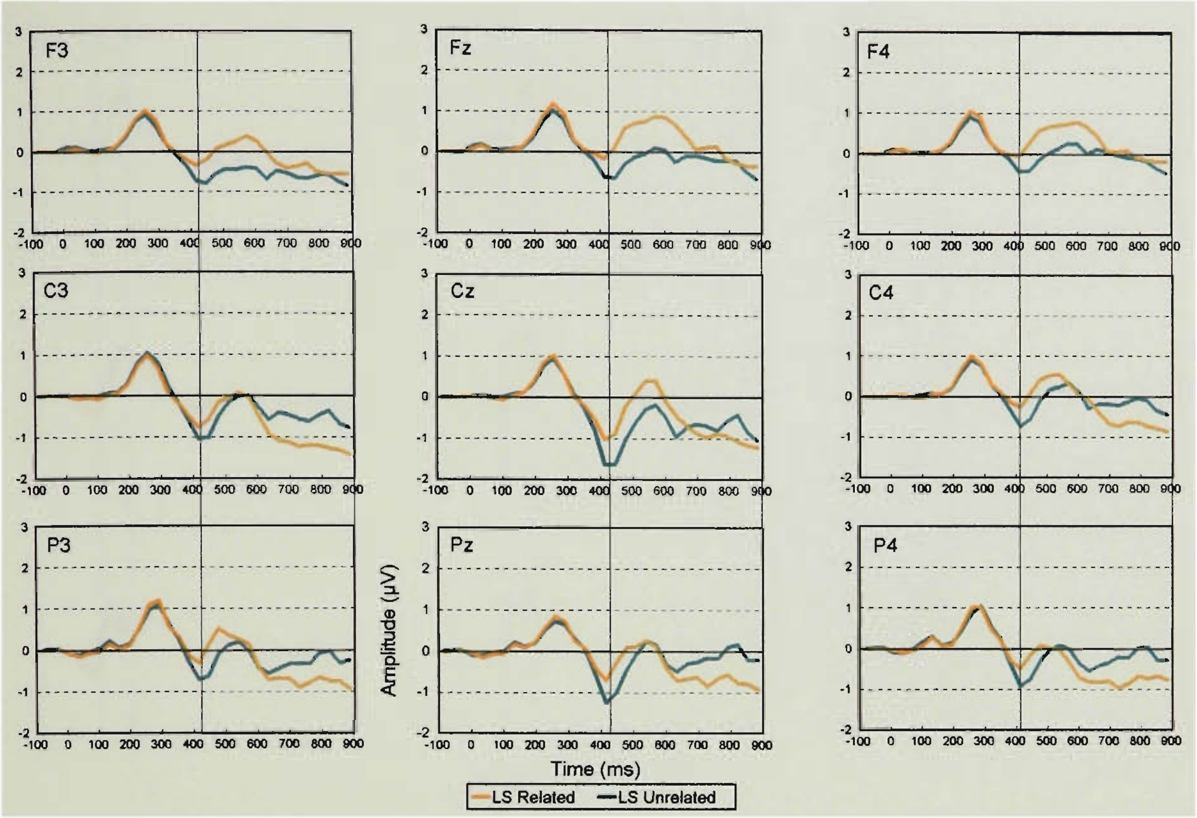


Figure 5.3. Grand average ERPs multiplied by Factor 1 (Slow Wave) of the rotated, rescaled component matrix.

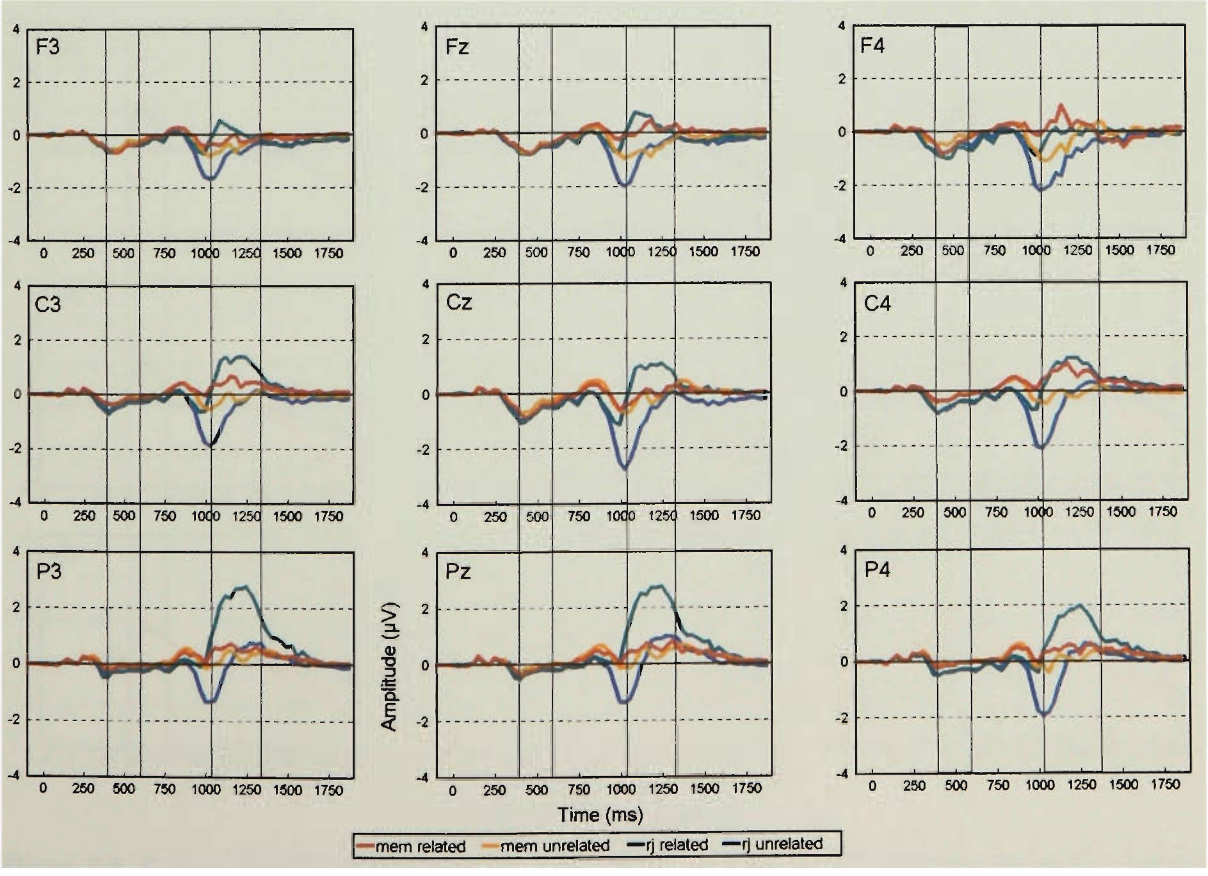


Figure 5.4. Grand average ERPs multiplied by Factor 2 (N400) of the rotated, rescaled component matrix.

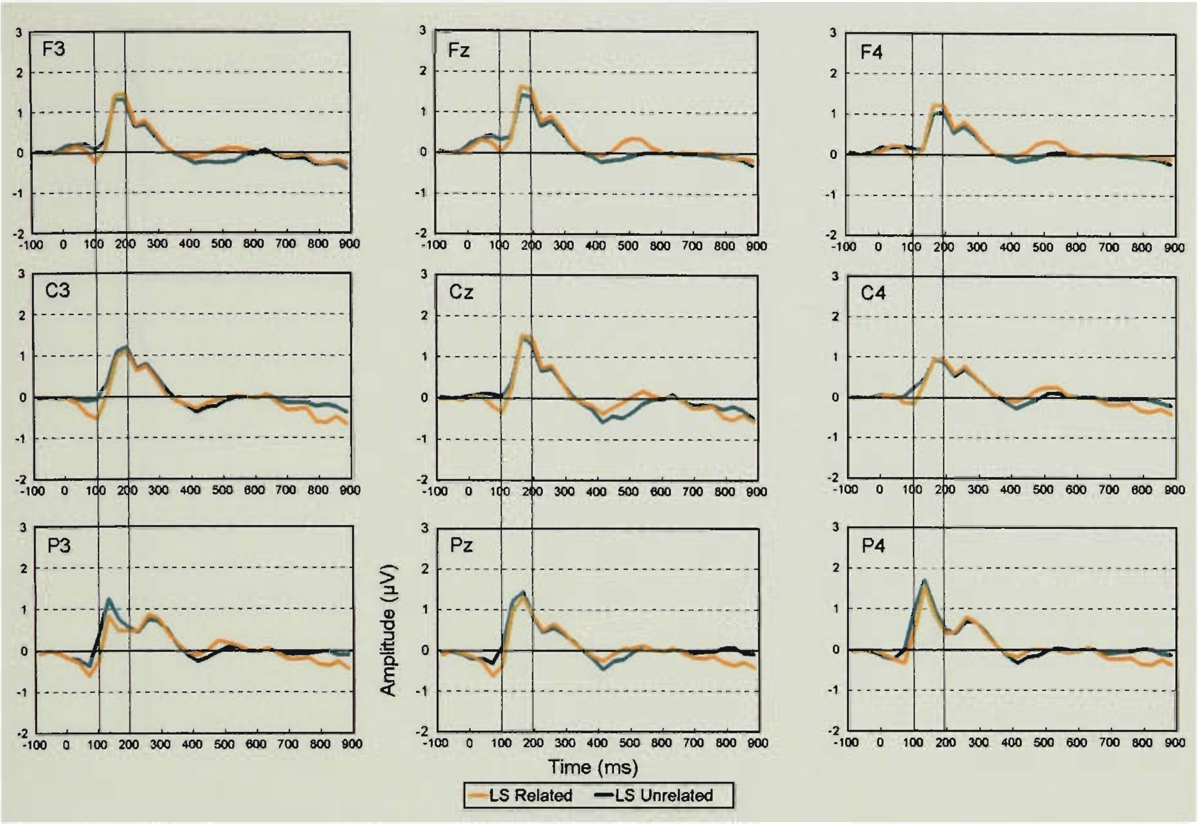


Figure 5.5. Grand average ERPs multiplied by Factor 3 (P1) of the rotated, rescaled component matrix.

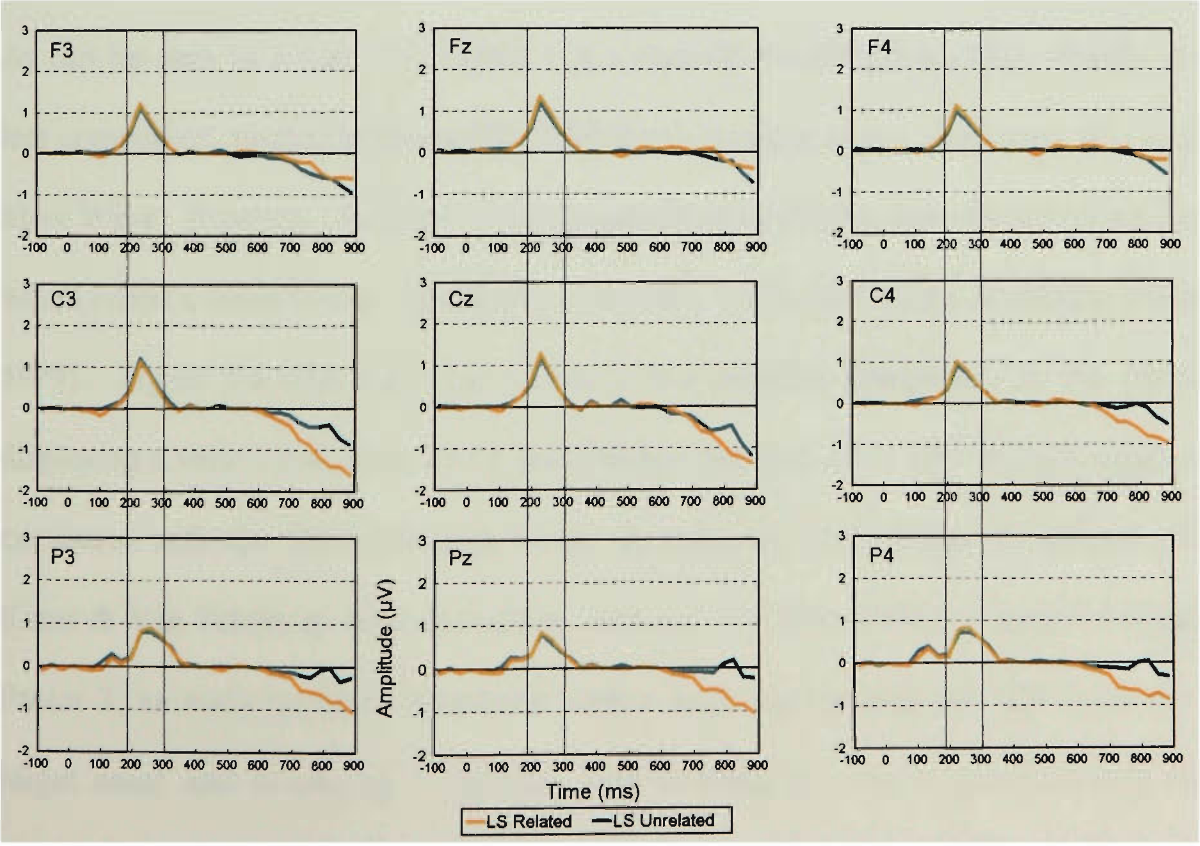


Figure 5.6. Grand average ERPs multiplied by Factor 4 (P2a) of the rotated, rescaled component matrix.

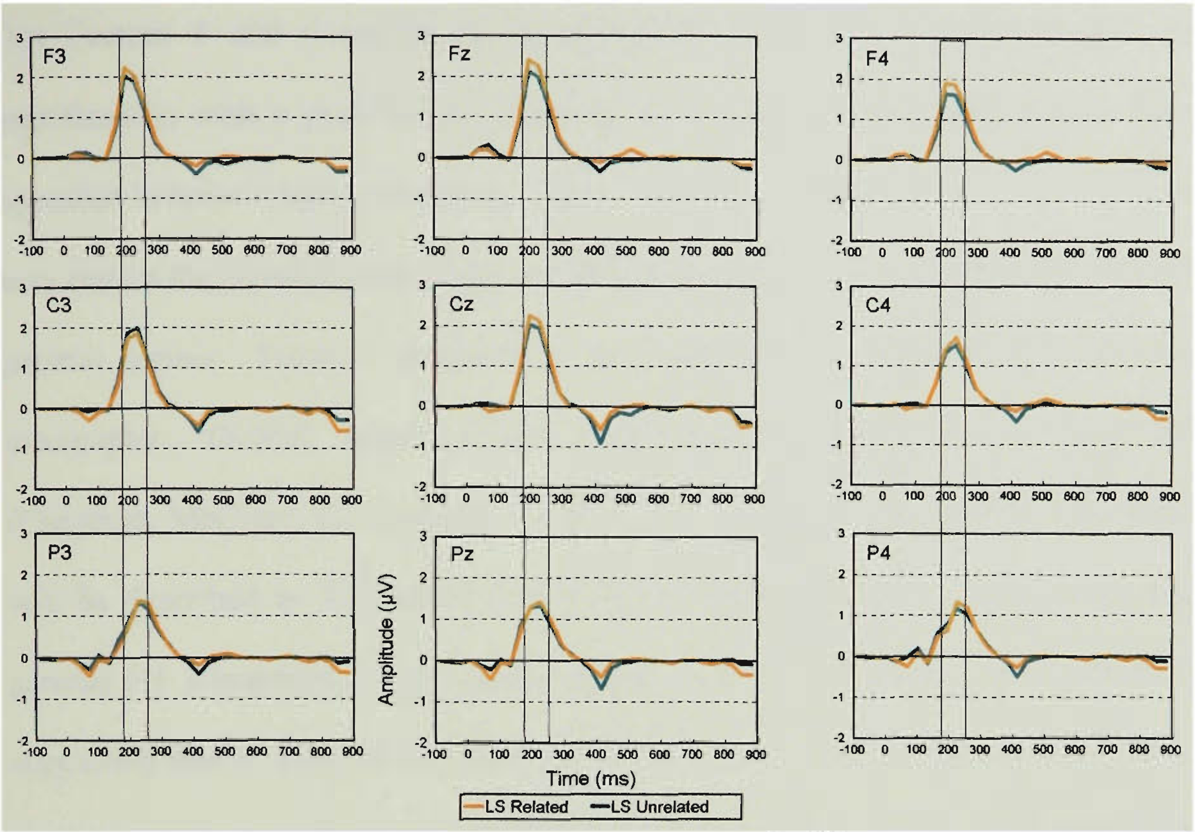


Figure 5.7. Grand average ERPs multiplied by Factor 5 (P2) of the rotated, rescaled component matrix.

As can be seen in Figure 5.3, Factor 1 is a broadly-distributed negative, slowly-varying late component ranging between 430 - 900 ms post target onset, most consistent with the Slow Wave. However, the Slow Wave is usually identified in memory recognition tasks, which report a more frontal topography (Holcomb, 1988; McCallum, as cited in Desmedt, 1979). Figure 5.4 illustrates that Factor 2 is a negative component in the waveform displaying a vertex maximum and a peak latency between 300 - 430 ms post target onset, consistent with the N400 (Benson, Kutas, & Hillyard, 1992; Kutas & Hillyard, 1980a; Kutas & Van Petten, as cited in Ackles, Jennings, & Coles, 1988). Figure 5.5 illustrates Factor 3, an early positive component with a peak latency between 100 - 190 ms post target onset and displaying a parietal right topography, most consistent with the P1 component (Kellenbach & Michie, 1996; Luck, as cited in Pashler, 1998; Mangun, Hillyard, & Luck, 1993; Vogel, Luck, & Shapiro, 1998). Figures 5.6 and 5.7 illustrate

that Factors 4 and 5 appear to be two distinct positive components that overlap significantly, with a peak latency between 190 - 300 ms post target onset. Factor 4 appeared to have a later peak latency than Factor 5, by approximately 30 to 40 ms, and may reflect the positive component occurring after the P1N1, and apparent only over the parietal region. Factor 5 appeared to be a similar component with a fronto-central topography. Overall, Factors 4 and 5 are most consistent with the P2 component (Chapman, McCrary, & Chapman, 1978; Taylor, Smith, & Iron, 1990). Therefore they will be described as P2a and P2 respectively, indicating factor order. The apparent parietal N1 component in the grand average did not appear as a factor in the PCA, suggesting that overlap of the P1 and the P2 complex may have led to its appearance. However, it is more likely that the component is actually an N1 and forms part of the P1N1 complex associated with early visuo-spatial attention that occurs before the completion of stimulus identification (Vogel, Luck, & Shapiro, 1998). Visual inspection of the grand mean average (see Figure 5.1) showed that this P1N1 complex was apparent only parietally, which is consistent with parietal-occipital activation in the visual cortex (Heinze, Mangum, Burchet, Hinrichs, Scholz, Munte, Gos, Scherg, Johannes, Hundeshagen, Gazzaniga, & Hillyard 1994; Luck, Chelazzi, Hillyard, & Desimore, 1997).

Factor	**Component**	**% Variance explained**	**Cumulative %**	**Latency Ranges (ms)**
Factor 1	Slow Wave	60.24	60.24	430-900
Factor 2	N400	12.88	73.12	300-430
Factor 3	P1	6.67	79.79	100-190
Factor 4	P2a	4.50	84.29	190-300
Factor 5	P2	3.32	87.61	190-260

Table 5.1. ERP components and latency ranges identified for target responses using PCA.

The latency ranges used in the analyses were determined by identifying the peak(s) associated with each factor and then minimising the component overlap between factors. For each scalp site, these ranges (see Table 5.1 above) were used to compute mean amplitude estimates of each component, and these were analysed as outlined above.

5.3.4. ERP DATA

5.3.4.1. P1

The P1 was larger parietally (1.11 μV) than frontally (0.50 μV) in the right hemisphere, with the effect reversed and more equipotential in the left hemisphere (0.63 μV and 0.51 μV respectively) [$F = 12.43$, $p < 0.01$]. Overall, P1 displayed a parietal right topography.

5.3.4.2. P2a

The P2a was larger frontally than parietally and this difference was larger over the midline region (0.89 μV) than for the mean of the left and right hemisphere (0.31 μV) [$F = 11.28$, $p < 0.01$]. That is, P2a displayed a frontal midline topography.

5.3.4.3. P2

The ANOVA did not show any significant results for this component, implying that overall the P2 was equipotential.

5.3.4.4. N400

N400 was larger over the midline region (-0.82 μV) than the mean of the left and right hemisphere (-0.28 μV) [$F = 12.94$, $p < 0.01$]. It was also larger over the central region (-0.97 μV) than the mean of the frontal and parietal sites (-0.20 μV) [$F = 32.61$,

$p < 0.001$]. The N400 was larger frontally (-0.32 μV) than parietally (0.06 μV) in the left hemisphere, with the effect reversed and smaller in the right hemisphere (0.08 μV and -0.14 μV respectively) [$F = 6.96$, $p < 0.05$]. The N400 was larger parietally (-0.84 μV) than frontally (-0.07 μV) over the midline region, with the effect reversed and smaller for the mean of the left and right hemispheres (-0.04 μV and -0.12 μV respectively) [$F = 17.55$, $p < 0.001$]. The N400 was larger centrally than for the mean of the frontal and parietal sites and this difference was larger in the left hemisphere (0.92 μV) than the right hemisphere (0.30 μV) [$F = 16.93$, $p < 0.001$]. Overall, the N400 displayed a fronto-central left to parietal midline topography.

5.3.4.5. SLOW WAVE

The Slow Wave was larger in the left (-0.83 μV) than the right hemisphere (-0.36 μV) [$F = 5.35$, $p < 0.05$], and more negative centrally (-0.85 μV) than the mean of the frontal and parietal sites (-0.49 μV) [$F = 6.59$, $p < 0.05$]. The central-frontal/parietal difference was larger over the midline region (0.65 μV) than the mean of the left and right hemispheres (0.22 μV) [$F = 13.38$, $p < 0.01$]. The Slow Wave was also larger parietally (-0.66 μV) than frontally (-0.03 μV) in the right hemisphere, with the effect reversed and smaller in the left hemisphere (-0.62 μV and -0.78 μV respectively) [$F = 10.95$, $p < 0.01$]. Parietally the Slow Wave was more negative for related (-0.94 μV) than unrelated responses (-0.33 μV), with the effect reversed and smaller frontally (-0.17 μV and -0.53 μV respectively) [$F = 6.97$, $p < 0.05$]. Overall, the negative Slow Wave displayed a left, central midline to parietal right topography. Parietally it was larger for related than unrelated words, and frontally this effect was reversed.

5.4. DISCUSSION

Five factors were extracted for target responses using PCA. Analyses of mean amplitudes of the ERP components, over the latency ranges determined by this procedure, yielded the following results: P1 displayed a parietal-right topography, consistent with visuo-spatial attention (Vogel, Luck, & Shapiro, 1998), P2a displayed a frontal-midline topography commonly associated with feature detection processes (Luck & Hillyard, 1994), and P2 was equipotential over the entire scalp. The topography of the N400 was fronto-central left to parietal-midline; the anterior N400 has been described as an index of word recognition in short-term memory, with posterior activation reflecting semantic processes in long-term memory (Stelmack & Miles, 1990). Finally, the Slow Wave displayed a left central-midline to parietal-right topography. The Slow Wave was the only component to show a relatedness effect and was larger parietally, and smaller frontally, for related compared to unrelated targets. In memory-recognition tasks, the Slow Wave has been associated with the retrieval of semantic information, and displays a frontal topography quite distinct from the parietal topography reported here (Holcomb, 1988; McCallum, as cited in Desmedt, 1979).

The current experiment was unsuccessful in replicating the findings of Kutas and Hillyard (1989). There was no priming effect on N400 amplitude, but the topography of this component is consistent with the literature. Visually, there was no evidence of a P3 component in the grand average ERPs for target responses. Also, no such component was extracted as a factor in the PCA, which implies that the delayed letter-search task was effective in delaying the decision-response P3 ERP component to avoid overlap with the N400. Although the task was letter search, semantic processing cannot be ruled out because of the relatedness effects obtained for the Slow Wave component and reaction

time. This issue will be addressed later in the general discussion.

An interesting issue raised by this study was whether the normal baseline adjustment prior to the target should be used. Since the prime provides the context for semantic priming - in the sense that it is actually causing the priming - it would seem important to analyse processing of the target uncontaminated by an immediately-prior baseline adjustment, which may distort vital aspects of the ERP signature of prime-processing apparent at the occurrence of the target, and hence yield incorrect results from analyses.

5.5. ANALYSIS 2

In the past two decades few electrophysiological studies have interpreted ERP indicators of processing associated with the prime word. This seems naïve when the literature suggests that the priming effect depends on how the prime is processed, often regardless of target processing (Friedrich, Henik, & Tzelgov, 1991; Henik, Friedrich, & Kellog, 1983; Henik, Friedrich, Tzelgov, & Tramer, 1994; Kellenbach & Michie, 1996). It would seem that a more-appropriate manner of investigating the priming effect would be to analyse the processing leading up to the effect, that is, the processing associated with the prime.

Also, contingent negative variation (CNV) has been correlated behaviourally with event anticipation, and was expected to be elicited by prime words in anticipation of target words (Birbaumer, Elbert, Canavan, & Rockstroh, 1990; Holcomb, 1988; Kellenbach & Michie, 1996; McCallum, as cited in Desmedt, 1979). This is an example of processing that flows through from prime to target, and its effects may be distorted using the baseline-adjustment procedure with a baseline immediately prior to the target.

In order to address these issues, separate exploratory PCAs were performed on the prime and target ERPs, again based on splitting the epoch spanning prime and target, but this time using a baseline-adjustment procedure with an overall baseline immediately prior to the prime rather than the target. The ERPs used in the PCA for the prime included the epoch commencing 100 ms prior to prime onset through to (but not including) the onset of the target at 700 ms. Those used in the PCA for the target commenced at target onset at 700 ms and ended at 1700 ms. There was no additional baseline adjustment using a baseline immediately prior to the target ERPs.

5.6. RESULTS

5.6.1. PRIME RESPONSES

The grand average ERPs (Figure 5.8) elicited to the primes associated with related and unrelated targets are remarkably similar to the grand average ERPs elicited by the related and unrelated targets themselves (see the previous analysis; Figure 5.3). A distinct P2 was elicited over the entire scalp. A P1 was evident parietally, followed by the P2. An N400 was apparent subsequent to the P2 and appeared largest over the central and parietal regions. This component was followed by a CNV.

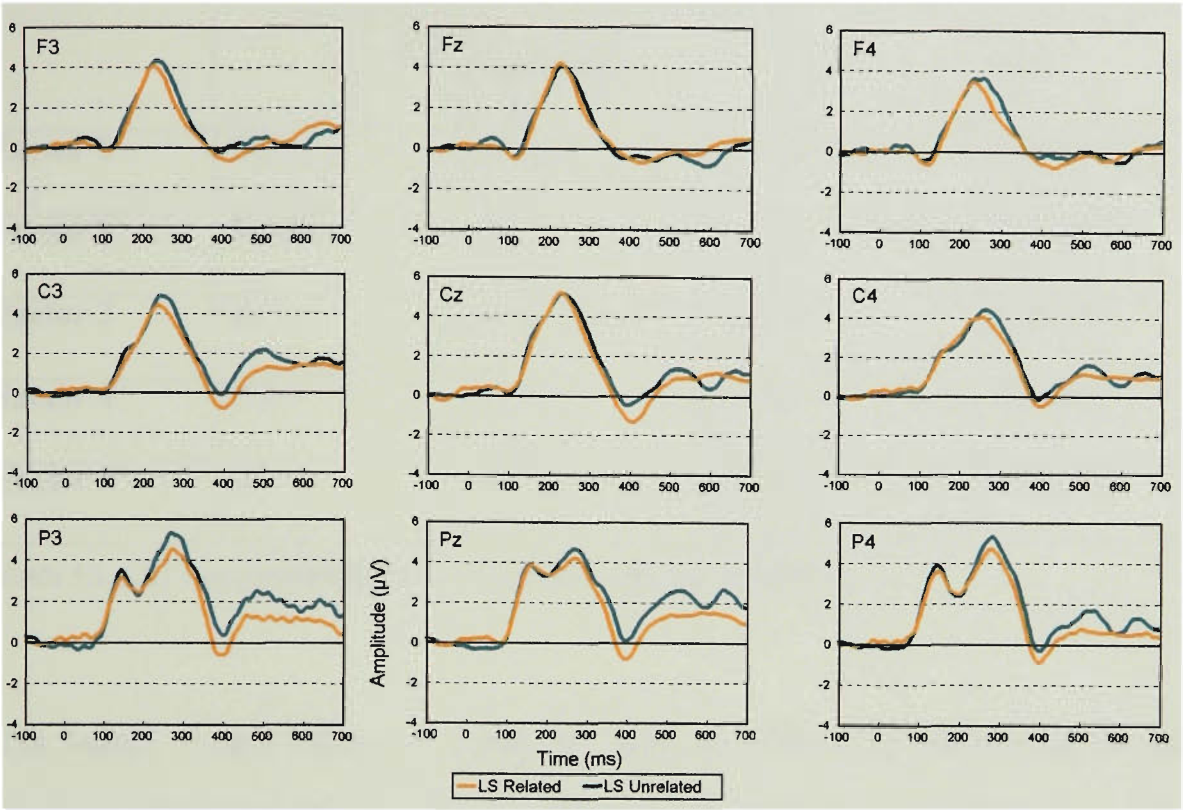


Figure 5.8. Grand average ERPs for primes associated with related and unrelated targets.

5.6.2. PCA

The resulting PCA output for primes is illustrated in Figure 5.9.

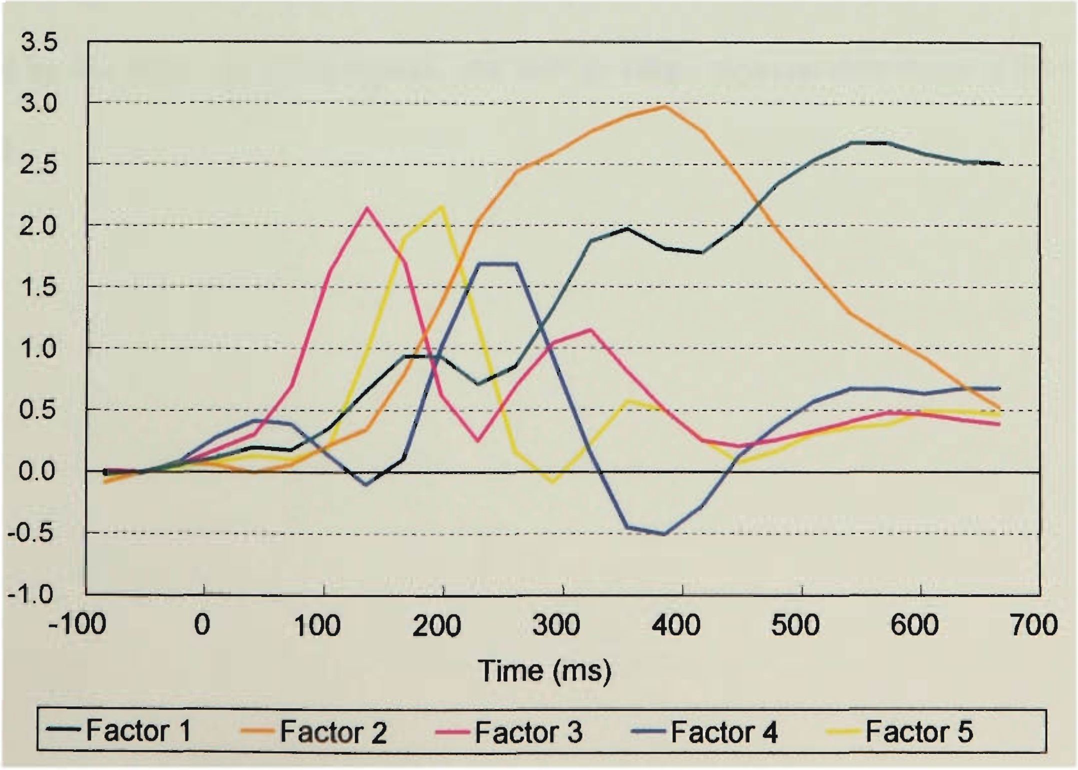


Figure 5.9. Factors extracted using separate principal components analysis on prime responses.

Factor	Component	% of Variance explained	Cumulative %	Latency range (ms)
Factor 1	CNV	63.36	63.36	460-700
Factor 2	N400	8.15	71.51	320-460
Factor 3	P1	6.66	78.17	110-180
Factor 4	P2a	4.69	84.53	180-290
Factor 5	P2	3.45	87.98	120-220

Table 5.2. ERP components identified for prime responses using PCA.

The latency ranges shown in Table 5.2 were determined by identifying the peak(s) associated with each factor and then minimising the component overlap between Factors illustrated in Figure 5.9. These latency ranges were used to compute mean amplitude estimates of each component used in the analyses. Figures 5.10 to 5.14 below were generated by multiplying the rotated, rescaled component matrix for each factor with the grand average ERPs, to allow an examination of the topography of the components derived by the PCA. In these figures, the latency range associated with the component is shaded.

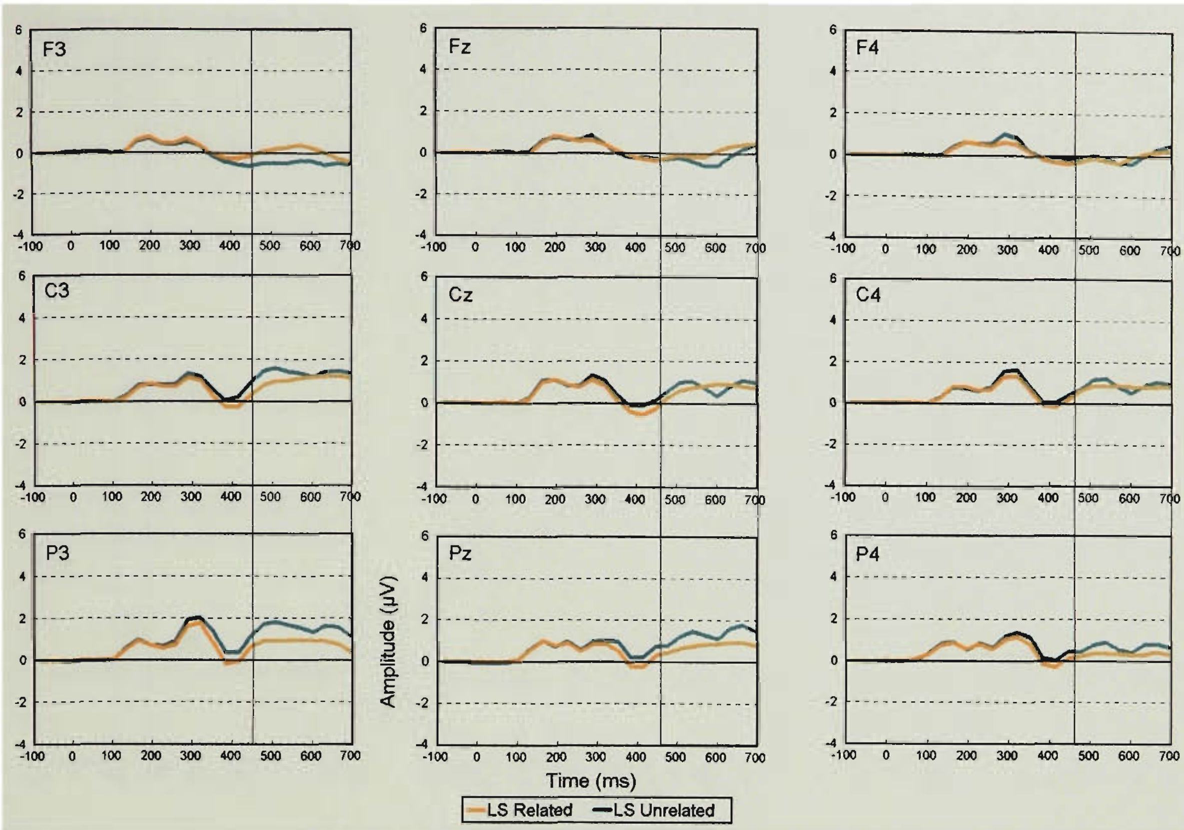
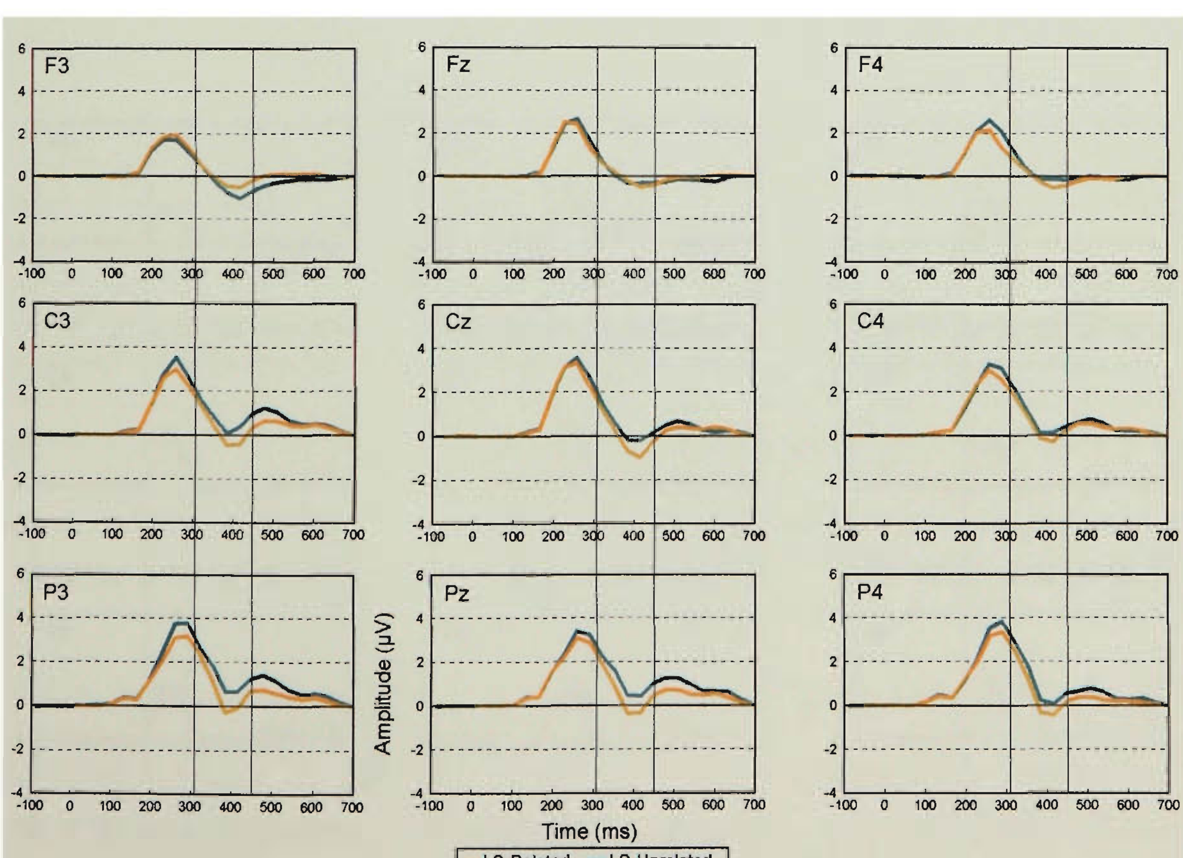


Figure 5.10. Grand average ERPs multiplied by Factor 1 (CNV) of the rotated, rescaled component



matrix. Figure 5.11. Grand average ERPs multiplied by Factor 2 (N400) of the rotated, rescaled component matrix.

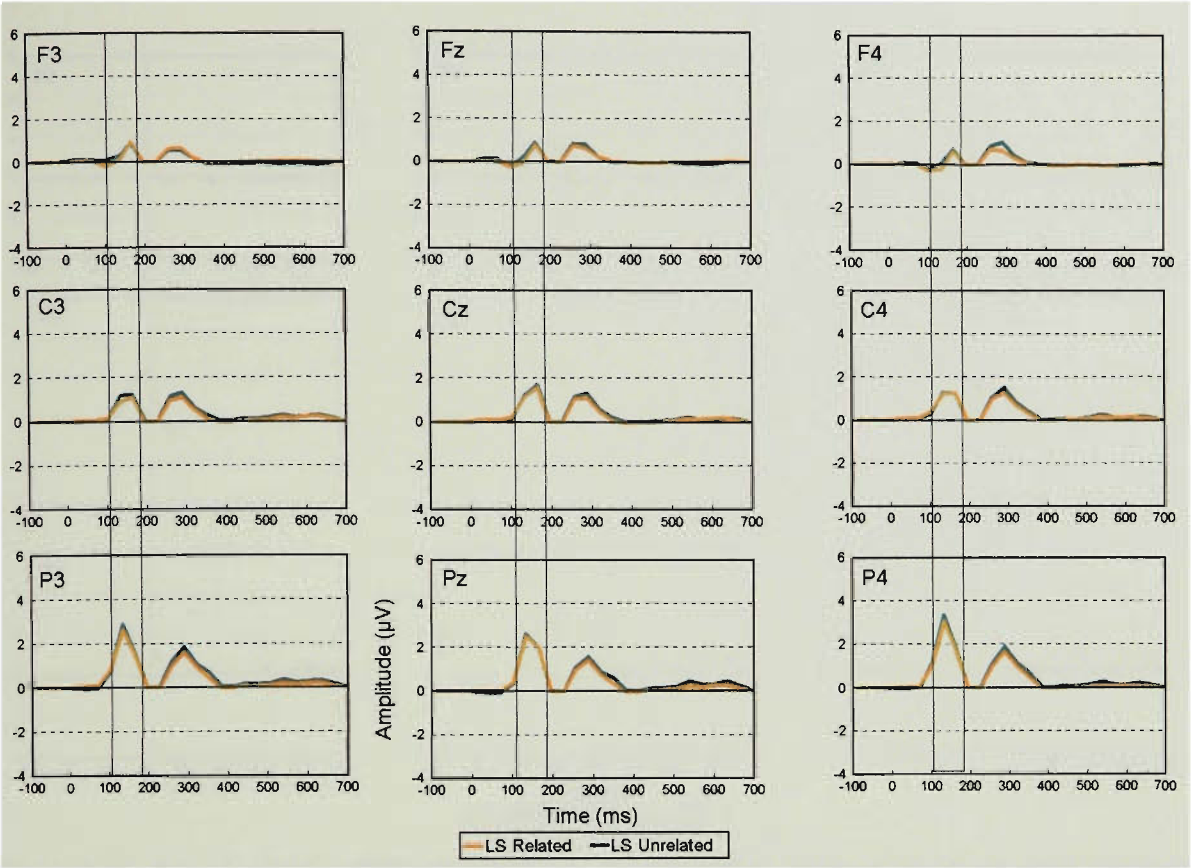


Figure 5.12. Grand average ERPs multiplied by Factor 3 (P1) of the rotated, rescaled component matrix.

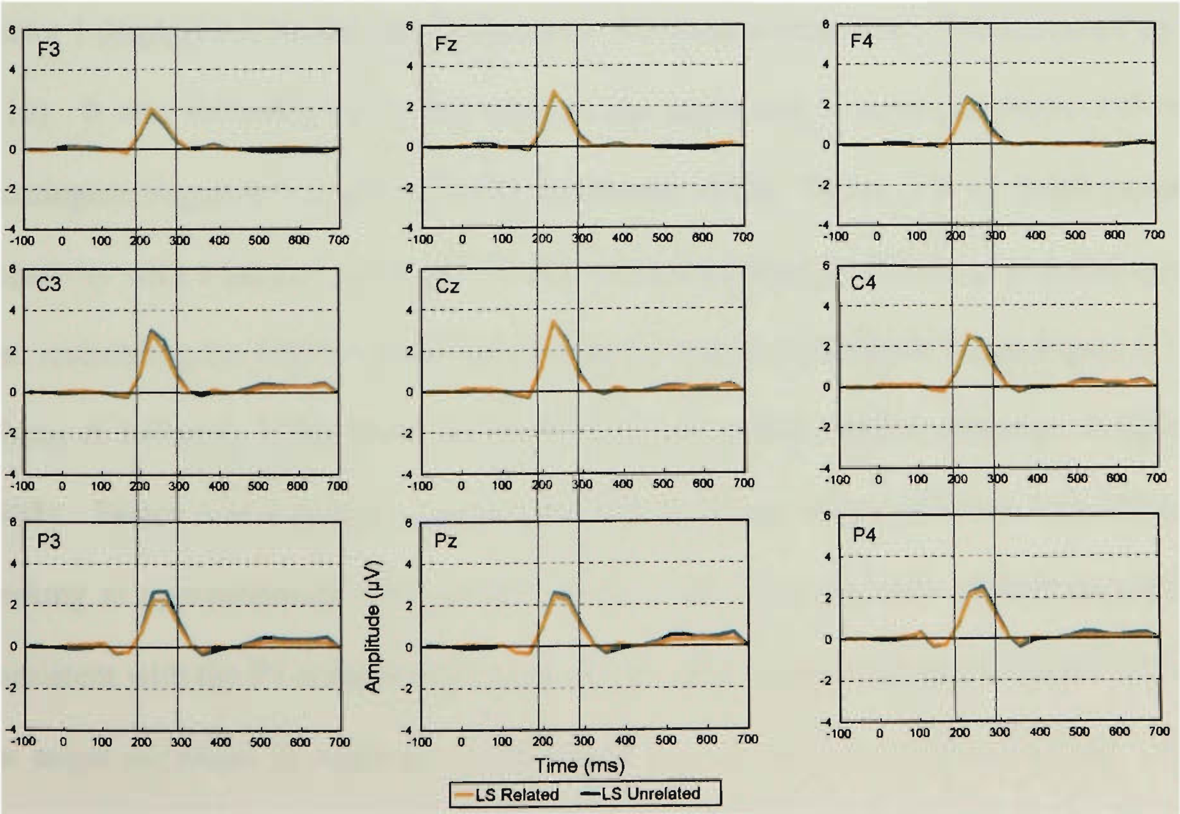


Figure 5.13. Grand average ERPs multiplied by Factor 4 (P2a) of the rotated, rescaled component matrix.

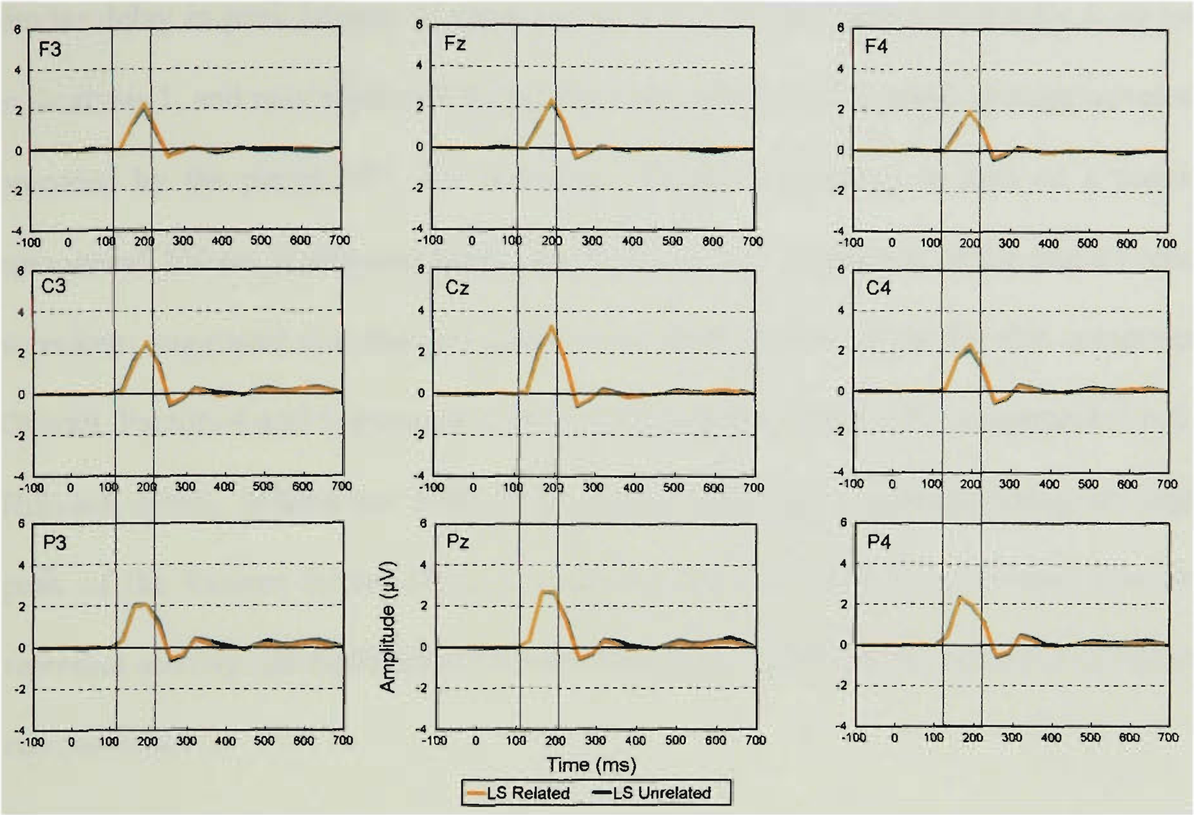


Figure 5.14. Grand average ERPs multiplied by Factor 5 (P2) of the rotated, rescaled component matrix.

Factor 1 displayed a frontal distribution over the latency range 400 - 700 ms (see Figure 5.10). It was elicited prior to the onset of the target and is most consistent with the Contingent Negative Variation (CNV) (Holcomb, 1988). Factor 2 is a central parietal negativity with a latency range of 320-460 ms and peaking at 400 ms post prime onset and resembling the N400 component elicited by targets in Analysis 1 (see Figure 5.11) (Kutas & Hillyard, 1984; Kutas & Van Petten, as cited in Ackles, Jennings, & Coles, 1988). Factor 3 is a positive component with a latency range between 110-180 ms, peaking at approximately 140 ms post prime onset and was only evident parietally, consistent with the P1 component displaying the same topography and a similar latency for target responses in Analysis 1 (see Figure 5.12) (Luck, as cited in Pashler, 1998; Vogel, Luck, & Shapiro, 1998). As in Analysis 1, Factors 4 and 5 were two distinct, but overlapping factors in the P2 latency range (160 - 320 ms). Factor 4 displayed a

similar delay in peak latency of approximately 40 ms compared with Factor 5, as seen in Analysis 1, and may represent the positive component in the grand average waveform preceded by the parietal P1, N1 complex. Factor 5 appeared to load on a positive component 200 ms post-prime onset (see Figure 5.12). Inspection of the grand average waveform suggested that the topography was more fronto-central for this component. Overall, Factors 4 and 5 appeared to be most consistent with the P2 component (Luck & Hillyard, 1994). Whilst this study is strictly determining components using the largest peak of the Factors in the PCA, it could be that factors with more than one peak represent activity that traditionally would have been interpreted in terms of two separate components.

5.6.3. TARGET RESPONSES

As apparent in Figure 5.15, the grand average ERPs elicited by related and unrelated targets in Analysis 2 are similar to the grand average ERPs elicited by related and unrelated targets in Analysis 1, and to the corresponding primes as discussed immediately above. A distinct P2 is again evident over the entire scalp. A P1-N1 complex was only elicited parietally, where it preceded the P2, possibly causing a delay in latency, and the N400 appeared maximal over the central and parietal regions. The Slow Wave appeared larger due to the extended epoch, which enabled fuller expression of this component.

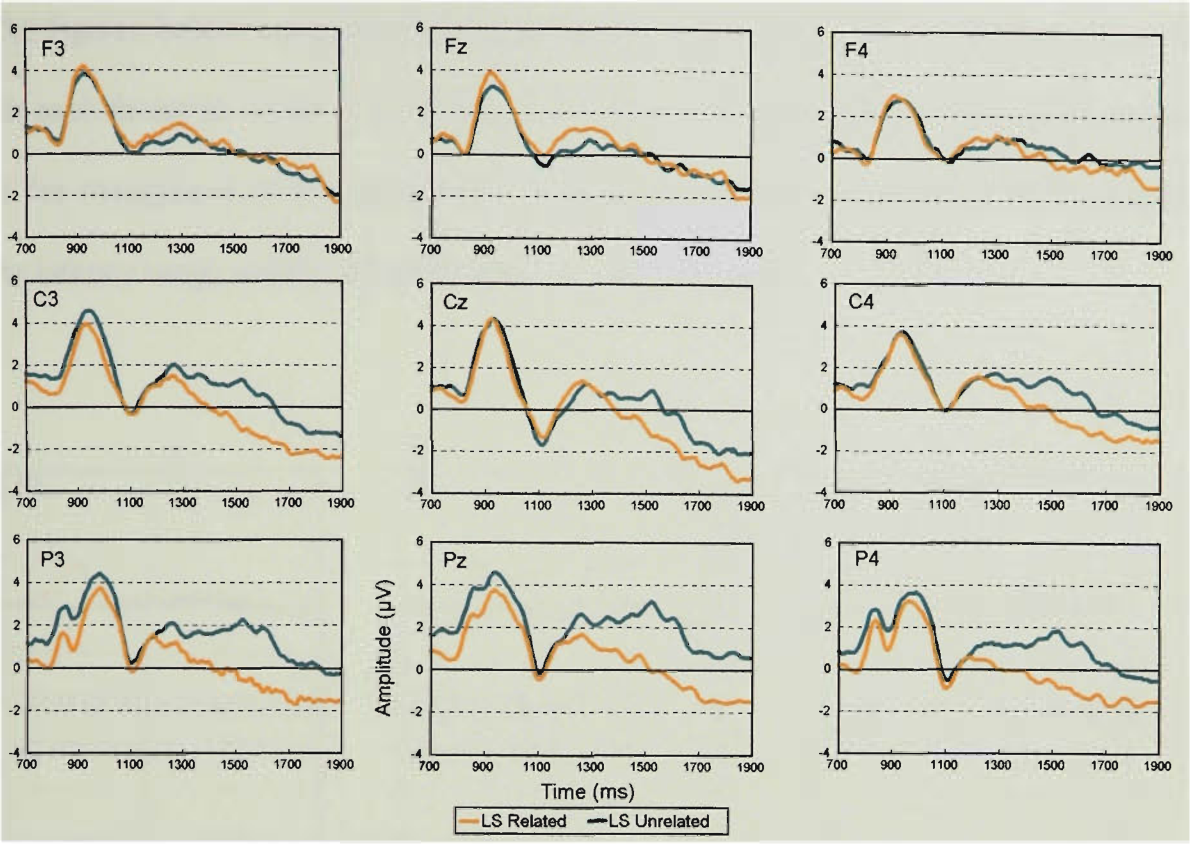


Figure 5.15. Grand average ERPs evoked by related and unrelated targets.

5.6.4. PCA

The resulting PCA output for target responses is illustrated in Figure 5.16.

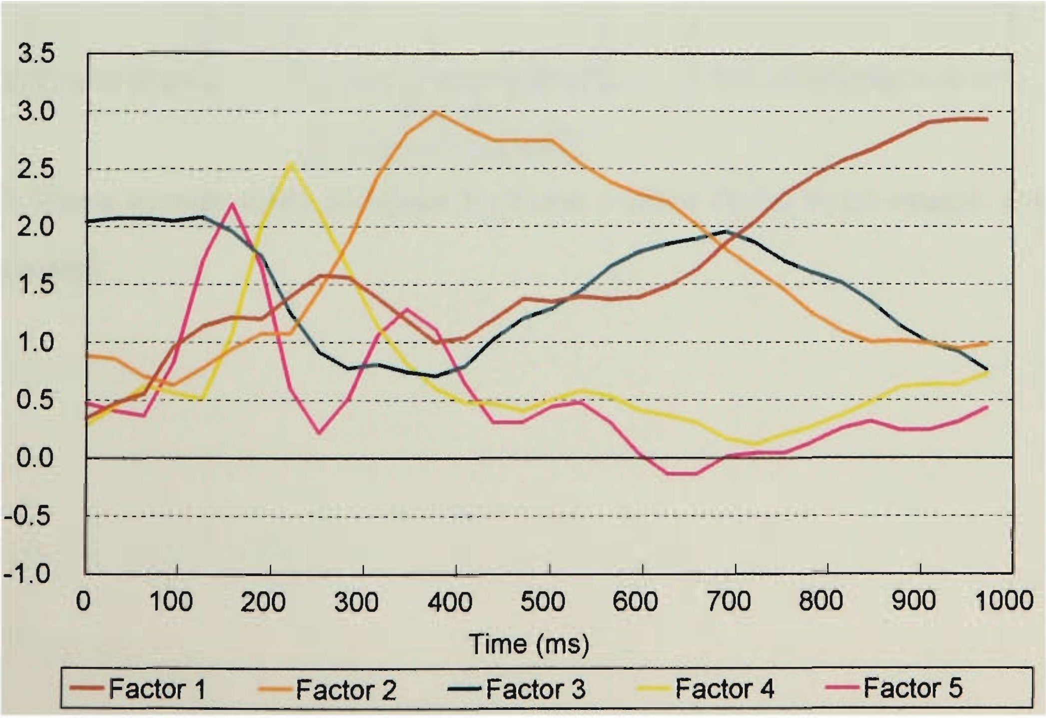


Figure 5.16. Factors extracted using separate principal components analysis on target responses.

The figures below were generated by multiplying the rotated, rescaled component matrix for each factor in Figure 5.16 above by the grand average ERPs, to allow an examination of the topography of the components derived by the PCA. In each of the figures below the latency range associated with the component is shaded.

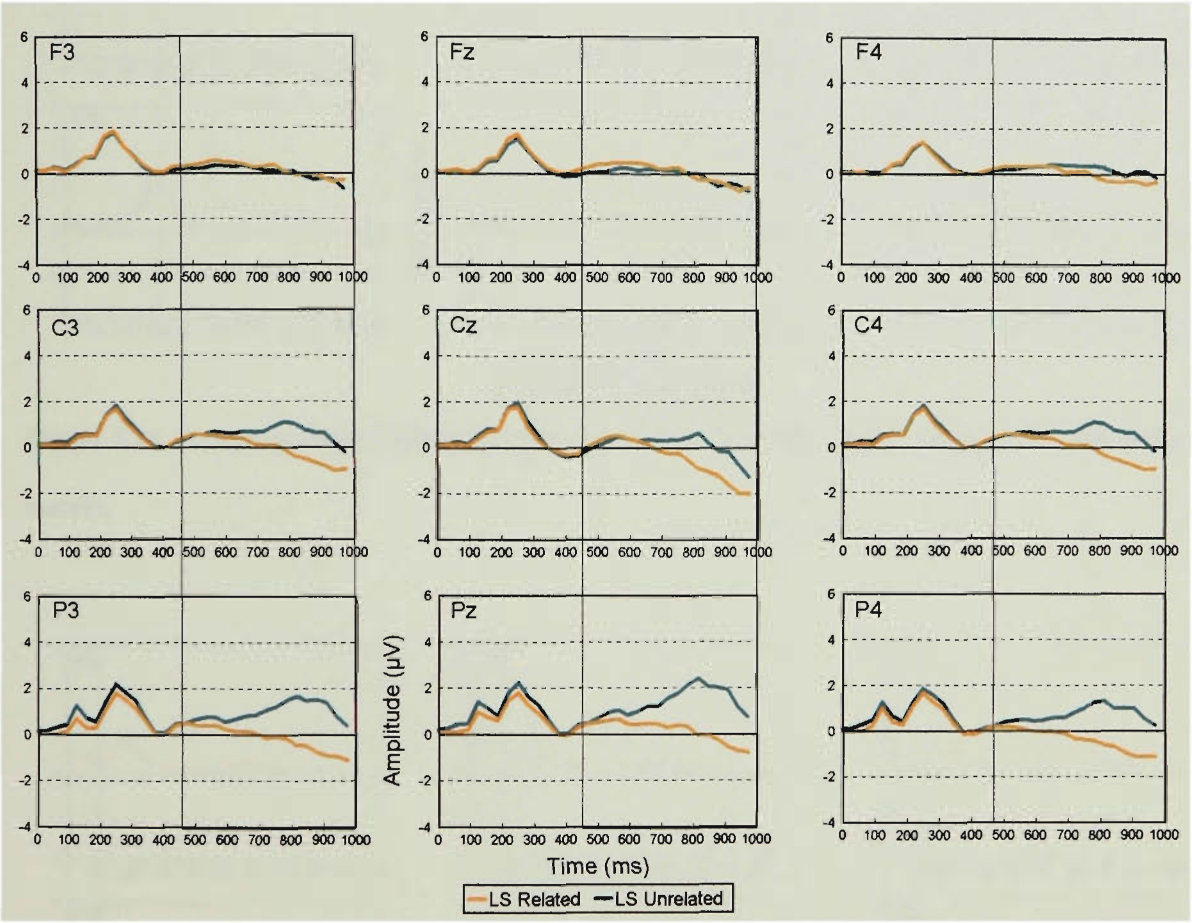


Figure 5.17. Grand average ERPs multiplied by Factor 1 (Slow Wave) of the rotated, rescaled component matrix.

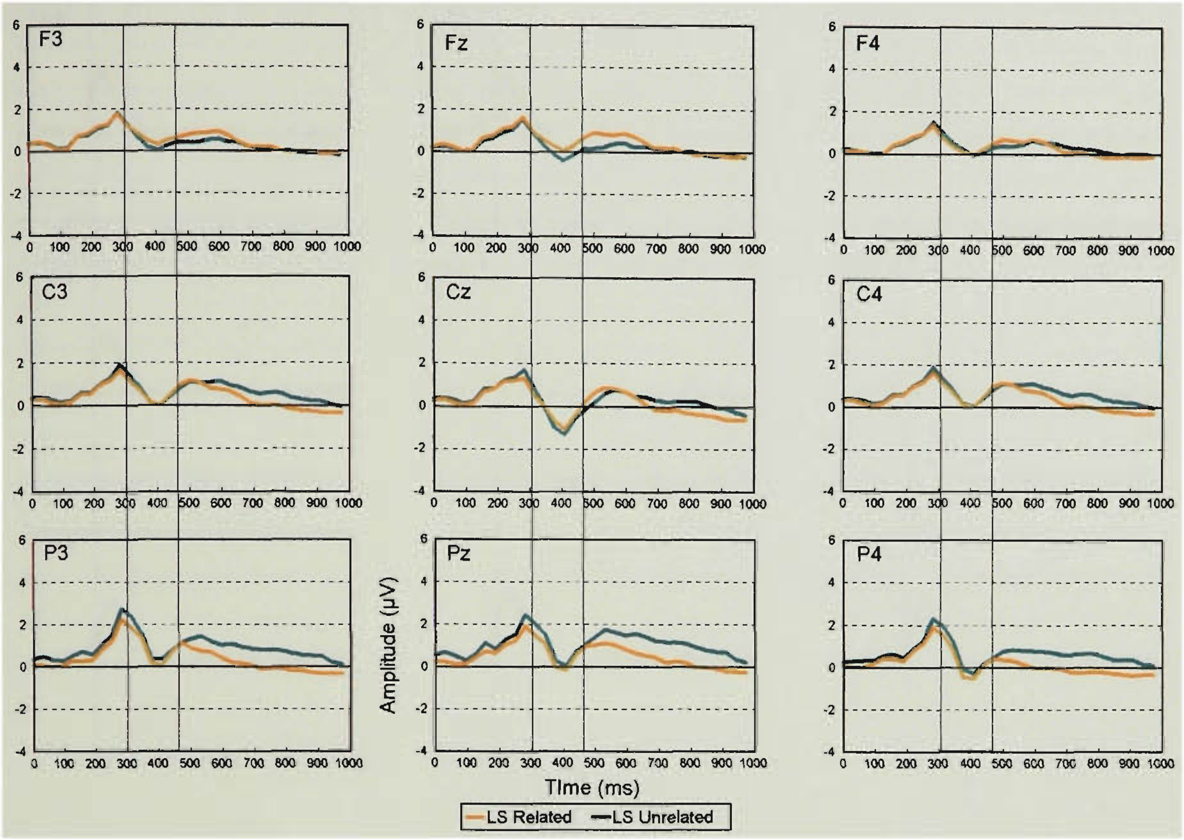


Figure 5.18. Grand average ERPs multiplied by Factor 2 (N400) of the rotated, rescaled component matrix.

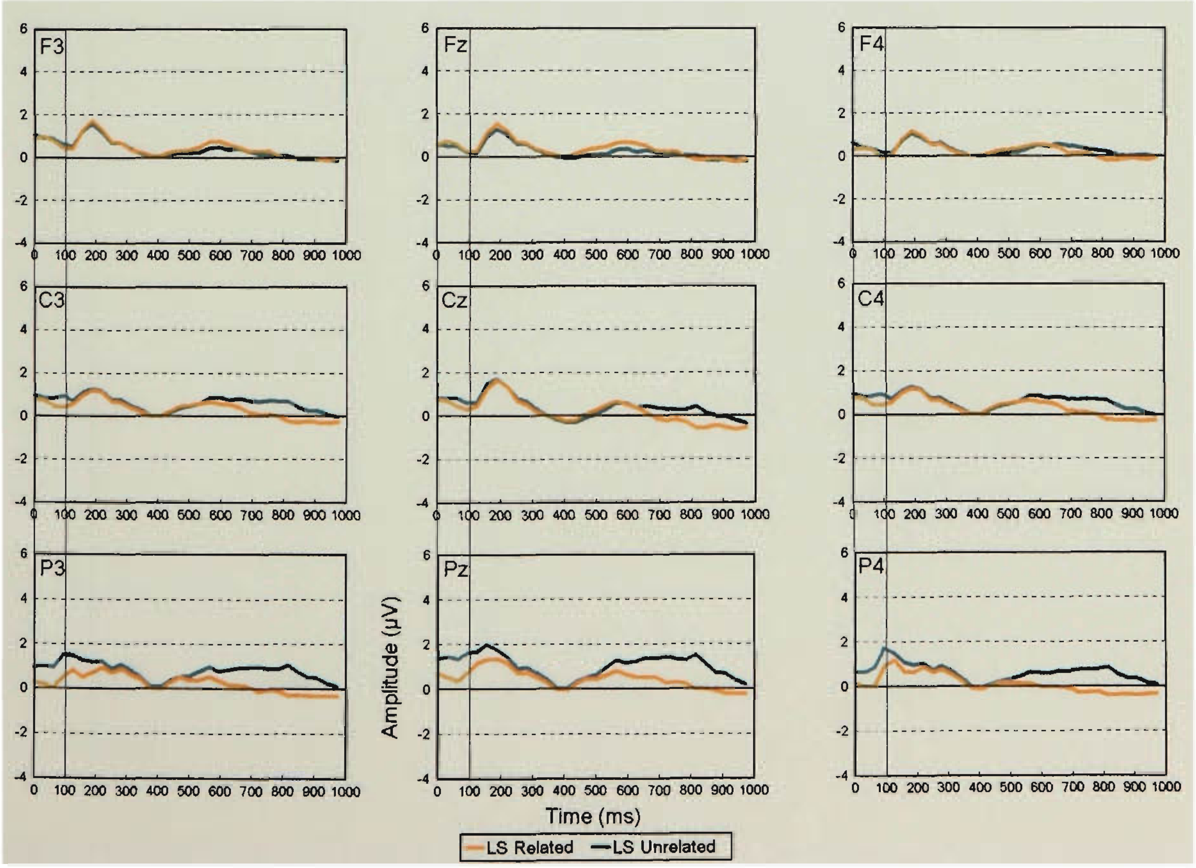


Figure 5.19. Grand average ERPs multiplied by Factor 3 (CNV) of the rotated, rescaled component matrix.

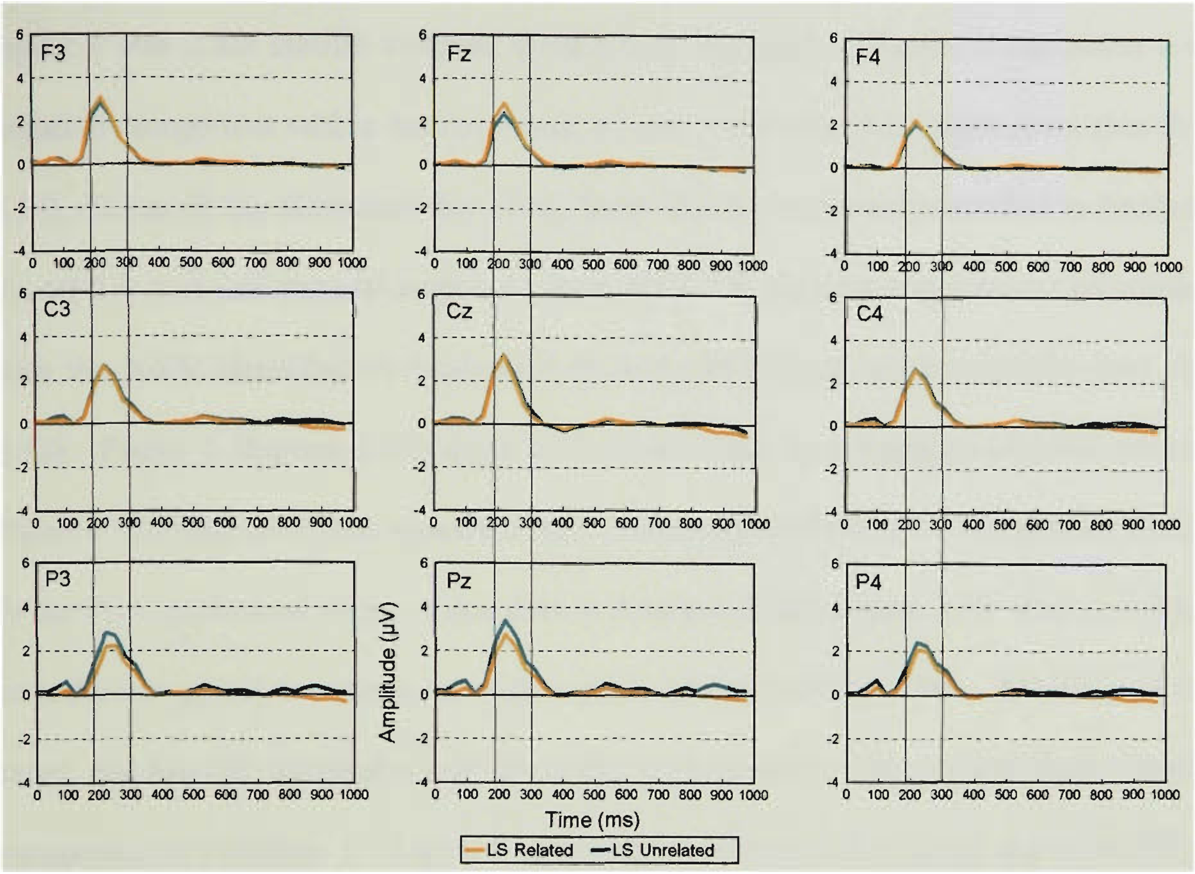


Figure 5.20. Grand average ERPs multiplied by Factor 4 (P2) of the rotated, rescaled component matrix.

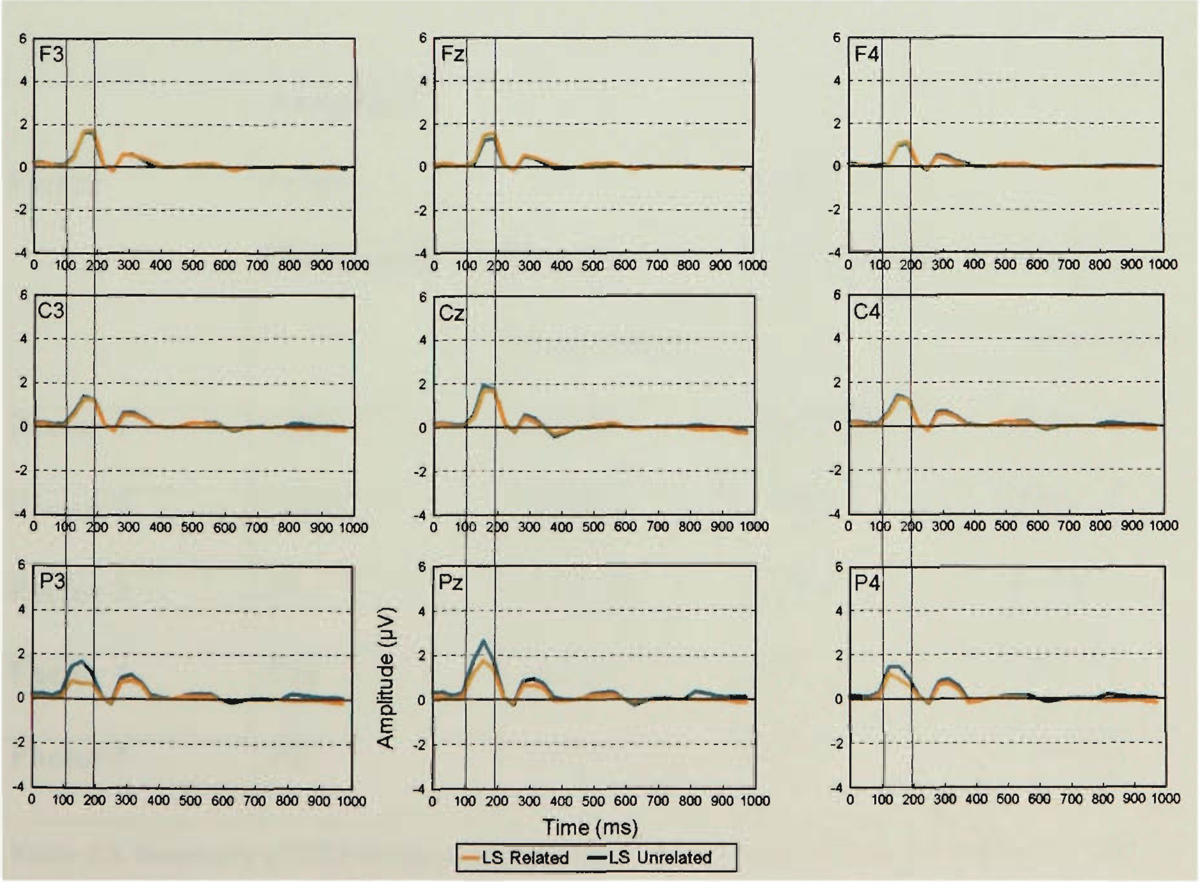


Figure 5.21. Grand average ERPs multiplied by Factor 5 (P1) of the rotated, rescaled component matrix.

Factor 1 and 2 are similar to those identified in Analysis 1. Factor 1 represents a slow negative component with a latency range of 430 – 900 ms post target onset (see Figure 5.17). It has all the characteristics of the Slow Wave component identified in Analysis 1. Factor 2 is a central parietal negativity peaking at 400 ms post target onset and consistent with the N400 identified in Analysis 1 in terms of latency and topography (see Figure 5.18). Factor 3 illustrated in Figure 5.19 above could be a baseline-adjusted version of Factor 4 in Analysis 1, and appears to be a continuation of the CNV component identified in the PCA performed on the prime data in Analysis 2 (see Figure 5.9). Factor 4 presents as a distinct positive component with a peak latency between 190 - 300 ms post target onset, and broadly distributed over the entire scalp, making it most consistent with the P2 component in Analysis 1. Factor 5 is a positive component peaking approximately 150 ms post target onset and only appears parietally, as did the P1 component identified in Analysis 1.

Factor	**Analysis 2** **Prime**		**Target**	
	Component	**Latency ranges (ms)**	**Component**	**Latency ranges (ms)**
Factor 1	CNV	460-700	Slow Wave	460-1000
Factor 2	N400	320-460	N400	300-460
Factor 3	P1	110-180	CNV	0-100
Factor 4	P2a	180-290	P2	190-300
Factor 5	P2	220-320	P1	100-190

Table 5.3. Summary of ERP components identified for prime and target responses using PCA.

As illustrated in Table 5.3, similar components and latencies have been identified for prime and target responses. P1, P2 and N400 are featured in both, with the CNV appearing to continue on from prime to target. The P2a identified for prime processing most likely reflects a distinct parietal component preceded by the P1-N1 complex, which may not have emerged in the target PCA because of the identification of the Slow Wave and CNV, slow-varying components that usually account for most of the variance.

5.7. DISCUSSION

5.7.1. PRIME PROCESSING

The approach in this second PCA was purely exploratory, so no statistical analysis of the response components was performed. In terms of the components identified, the grand average ERPs elicited by primes in Analysis 2 are similar to the grand average ERPs elicited by targets in Analysis 1 and Analysis 2. That is, both primes and targets elicited similar P1, P2, and N400 components (see Table 5.4), as illustrated by the respective PCAs.

Factor	Analysis 2				Analysis 1	
	Prime		Target		Target	
	Component	Latency ranges (ms)	Component	Latency ranges (ms)	Component	Latency ranges (ms)
Factor 1	CNV	460-700	Slow Wave	460-1000	Slow Wave	430-900
Factor 2	N400	320-460	N400	300-460	N400	300-430
Factor 3	P1	110-180	CNV	0-100	P1	100-190
Factor 4	P2a	180-290	P2	190-300	P2a	190-300
Factor 5	P2	220-320	P1	100-190	P2	190-260

Table 5.4. Summary of ERP components identified for prime and target responses in Analysis 2 and target responses in Analysis 1 using PCA.

5.7.2. TARGET PROCESSING

The second method of averaging the data used a baseline preceding the prime rather than a baseline immediately-prior to the target. The resulting PCA was broadly similar to results from the initial method in which target-baseline adjustment was used immediately-prior to the target. Similar components were identified: P1, P2, N400, Slow Wave (see Table 5.4). However, P2a (Factor 4) identified in the PCA of Analysis 1 appeared to be a baseline-adjusted version of the CNV (Factor 3) identified in the PCA of Analysis 2. This suggests that the baseline adjustment method used in Analysis 1 may have resulted in an erroneous interpretation of Factor 4 as a P2 component when it appears to be a continuation/ resolution of the CNV elicited by the prime that extends into the epoch of the target.

5.7.3. GENERAL DISCUSSION

The CNV associated with prime processing appears to extend beyond the onset of the target. Hence, establishing a latency range for analysis of the CNV that falls entirely within the epoch corresponding to the prime may not provide an adequate representation of what is occurring.

When considering the PCAs associated with the prime and target responses, it would appear that some of the components extracted in the analysis of the prime response are very similar to those in the target response, indicating that similar processes are being used in the cognitive processing of both prime and target.

It has not been established whether the negativity elicited by prime and target words in the N400 latency range reflects the same component or different components. Therefore there is a need to establish whether the component reflecting processing of the prime in the N400 latency range is the same as that for the target over the same latency range. This same principle applies to the other components identified. The current findings also show a need to address the issue of distortion due to baseline-adjustment.

5.8. ANALYSIS 3

Some studies have used the conventional method of visual inspection to identify ERP components associated with both prime and target processing (Brown, Hagoort, & Chwilla, 2000; Kellenback & Michie, 1996). By applying principal components analysis over an epoch encompassing both the prime and target, the current analysis seeks to objectively determine whether the prime and target words elicit the same ERP components, which would be apparent in a pairing of peaks in the same PCA component

over latency ranges corresponding to the prime and target responses. If this were to be the case, then it would imply that the same underlying processes are involved in the cognitive processing of the prime and target. The focus will be on whether the negativity in the N400 latency range elicited by prime words is separable from that elicited by the target words.

Another consideration arises from the fact that the ERPs associated with processing of the prime and target are not often averaged in a single epoch. As reported in the previous analysis, using target-baseline adjustment when only analysing the target may distort the impact of event-related potentials, such as the CNV, peaking around the point where target-baseline adjustment usually occurs. "Baseline" implies a period of inactivity prior to stimulus onset, but it would appear that this period of inactivity does not exist for targets. This problem would be overcome by performing the PCA over the entire epoch, spanning both prime and target, with a single pre-prime baseline. This could provide a statistically-powerful means of addressing this issue and others raised earlier.

The analysis consisted of 2 levels of relatedness (related, unrelated) x 2 word types (prime, target) x 11 electrodes x 15 subjects, forming 660 cases. Every eight points in the data set were averaged in order to perform PCA from 100 ms pre-prime onset to 1200 ms post-target onset (Coles, Gratton, Kramer, & Miller, as cited in Coles, Donchin, & Porges, 1986). PCA was performed on the covariance matrix using SPSS-X V8 with varimax rotation of factors.

5.9. RESULTS

5.9.1. ERPs

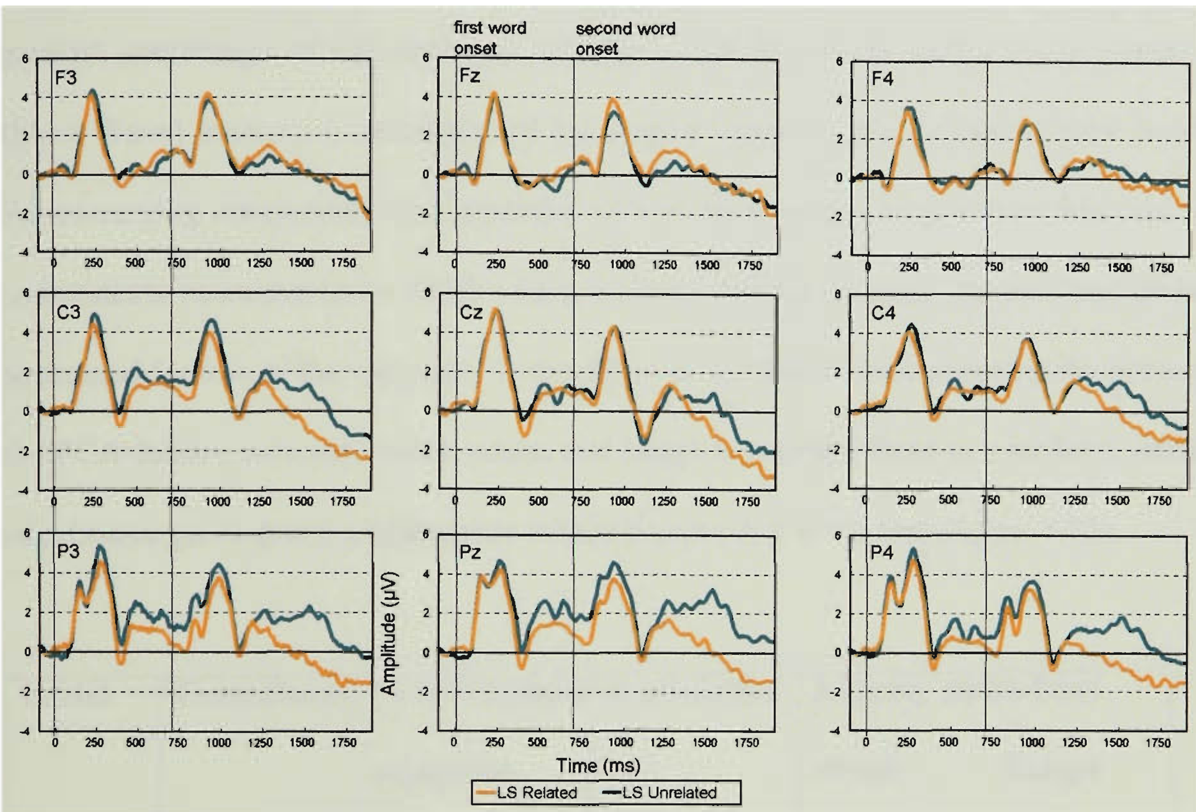


Figure 5.22. Grand average ERPs evoked by related and unrelated prime-target pairs.

5.9.2. PCA

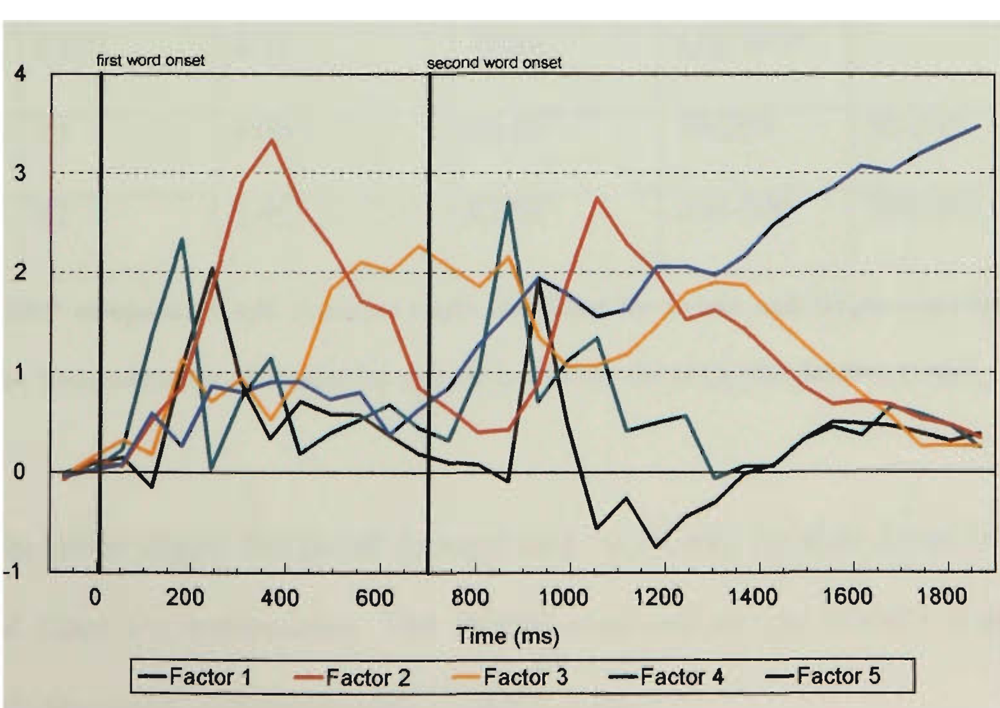


Figure 5.23. Factors extracted using PCA on prime and target responses across a single epoch.

The latency ranges of the components were derived by minimising the overlap between factors identified using the PCA (see Figure 5.23) and are shown in Table 5.5. The PCA (see Figure 5.23) produced a similar outcome to that of the previous analyses in that the greatest percentage of variance was accounted for by the slowest-varying component (Slow Wave) because it encompassed the largest region of the voltage X time function. Faster-varying components that extended over short temporal ranges then followed; such components encompassed a smaller region of the voltage by time function and therefore accounted for less of the variance. It should be noted that when comparing the portions of the PCA factors associated with prime and target responses, there is a striking similarity of prime/target response components within Factors 2, 4 and 5 (see Figure 5.23).

Factor	**Component**	**% of Variance explained**	**Cumulative %**	**Latency range (ms)**	
				Prime	**Target**
Factor 1	Slow Wave	65.66	65.66		475-1000*
Factor 2	N400	9.35	75.01	300-525	300-475
Factor 3	CNV	4.83	79.84	525-700*	
Factor 4	P1	4.69	84.53	50-200	50-200
Factor 5	P2	3.45	87.98	200-300	200-300

Table 5.5. ERP components and latency ranges identified for prime and target responses using PCA. *Note: These components displayed a single peak over the respective latency range.

The figures below depict the grand average ERP multiplied by each factor in order to define and label the components. The shaded area reflects the latency range of the components identified, as summarised in Table 5.5 above.

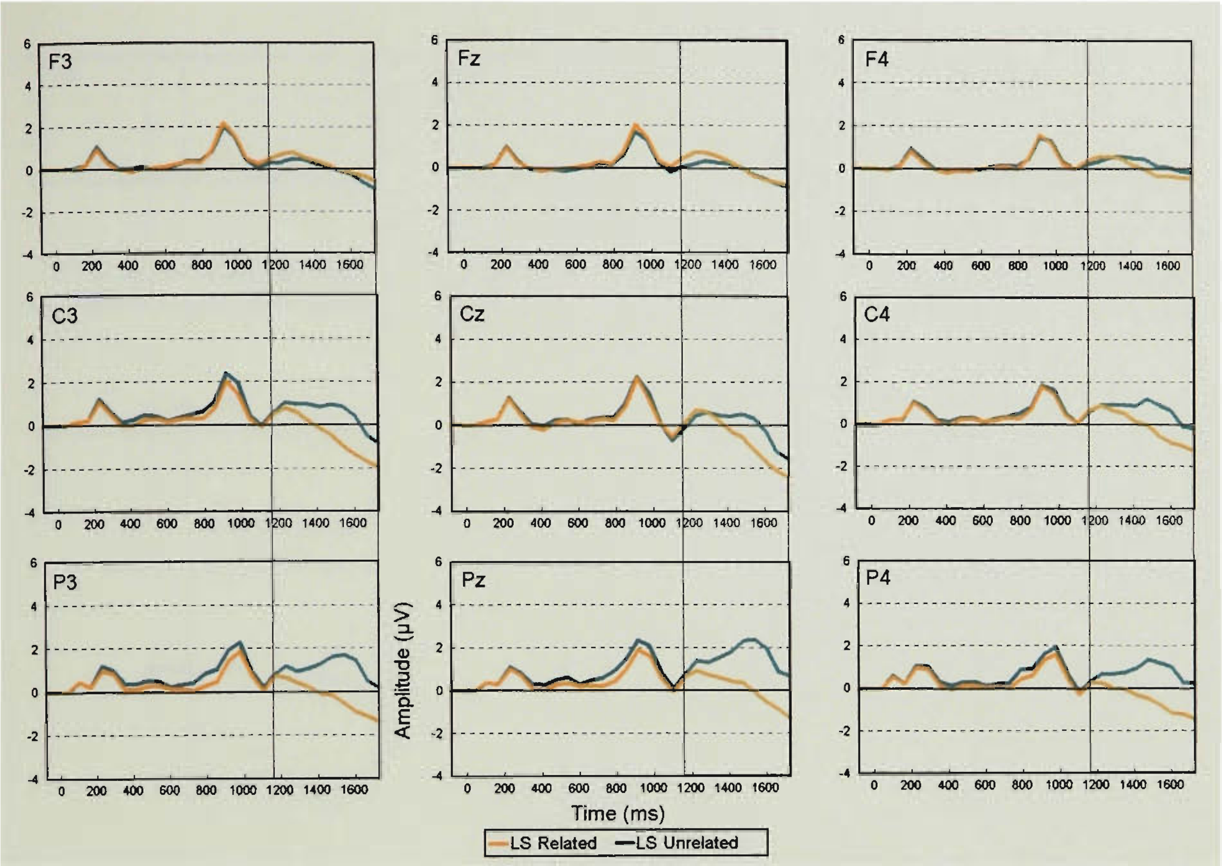


Figure 5.24. Grand average ERPs multiplied by Factor 1 (Slow Wave) of the rotated, rescaled component matrix.

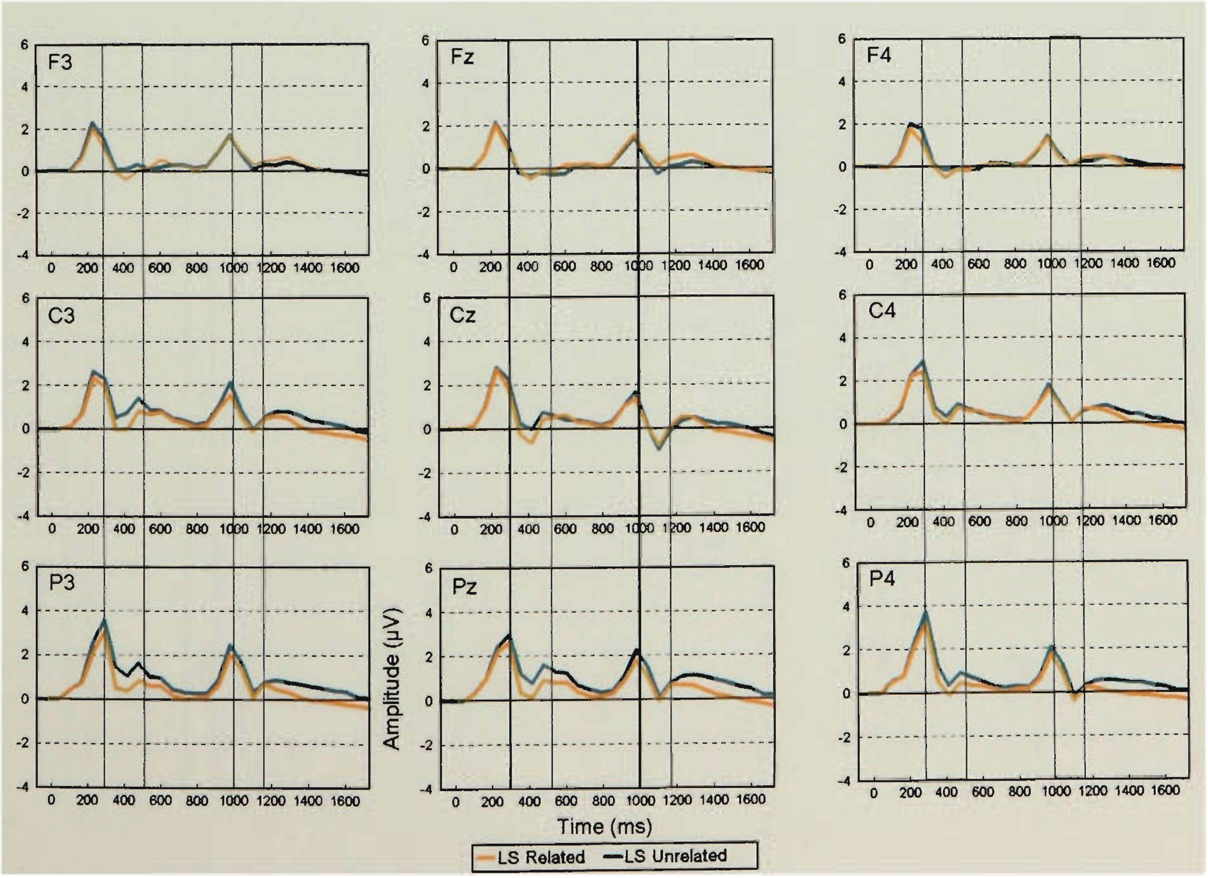


Figure 5.25. Grand average ERPs multiplied by Factor 2 (N400) of the rotated, rescaled component matrix.

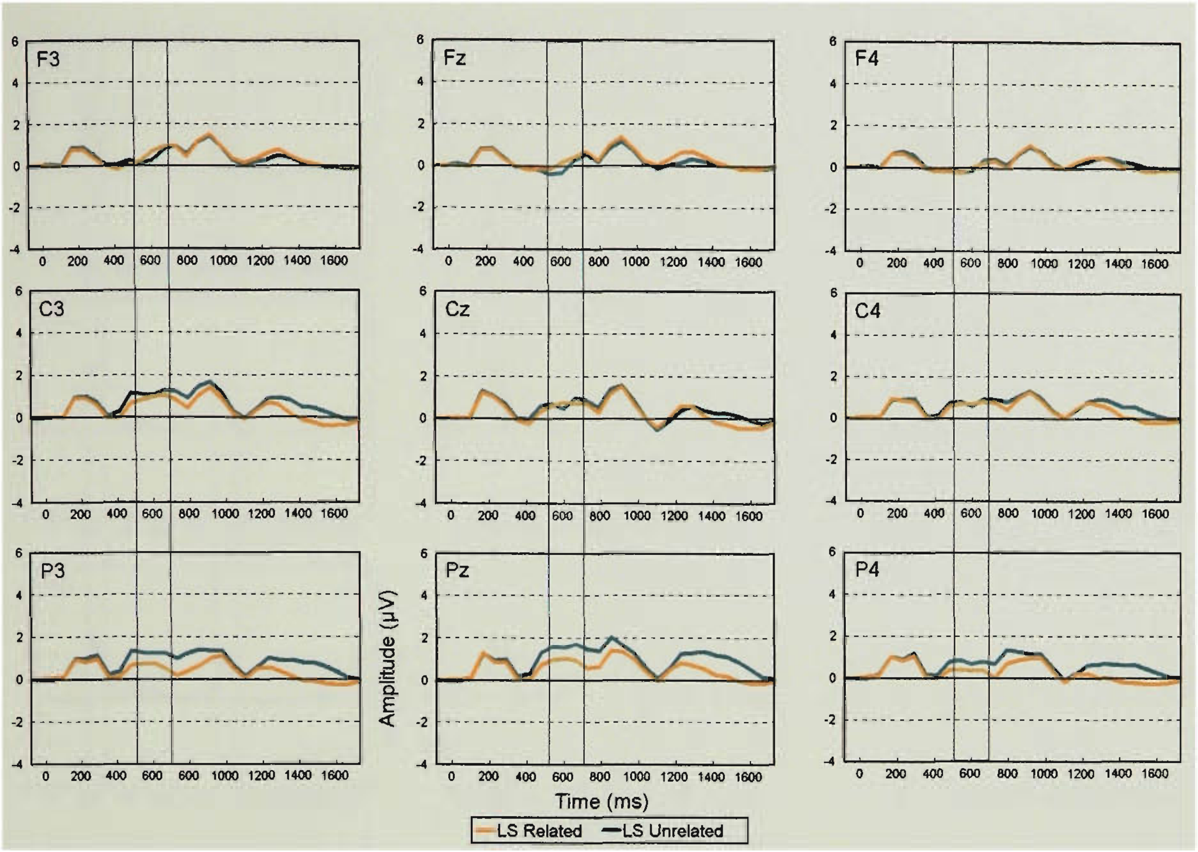


Figure 5.26. Grand average ERPs multiplied by Factor 3 (CNV) of the rotated, rescaled component matrix.

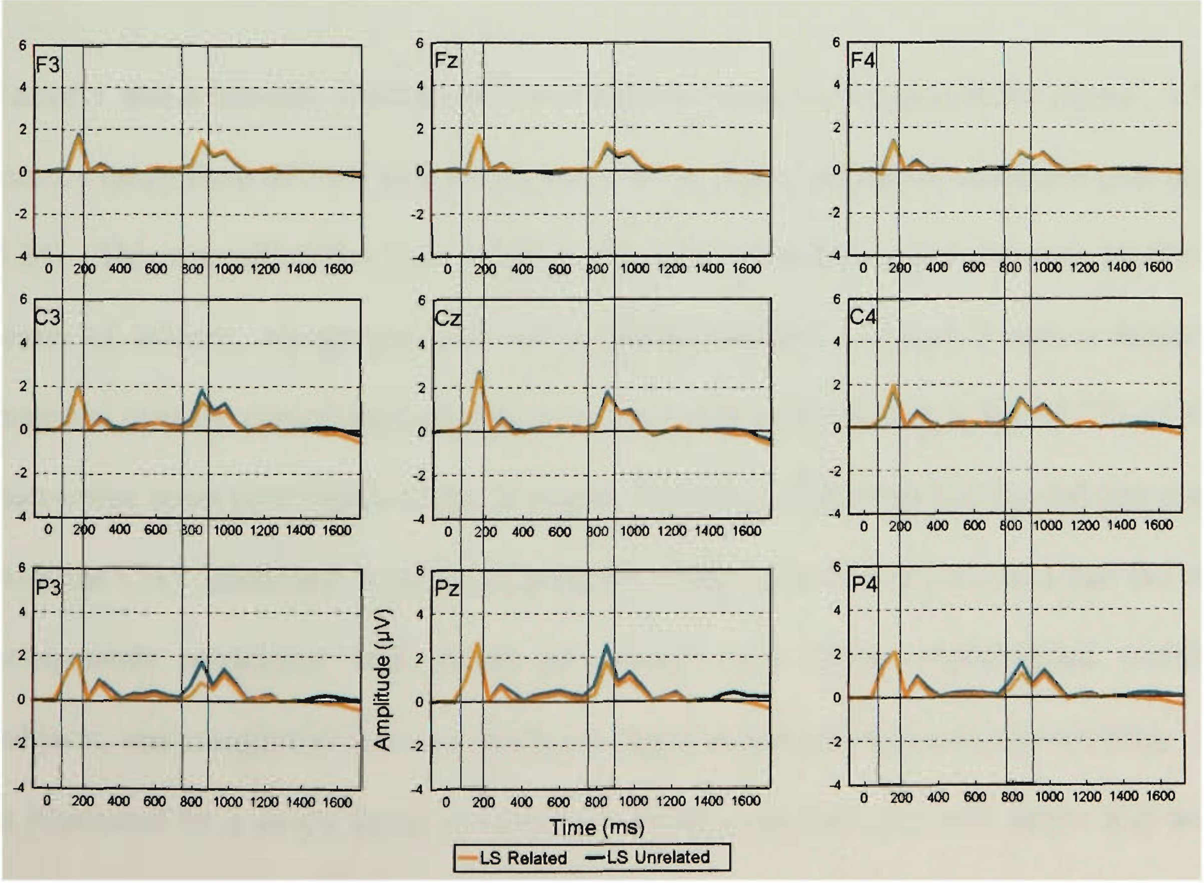


Figure 5.27. Grand average ERPs multiplied by Factor 4 (P1) of the rotated, rescaled component matrix.

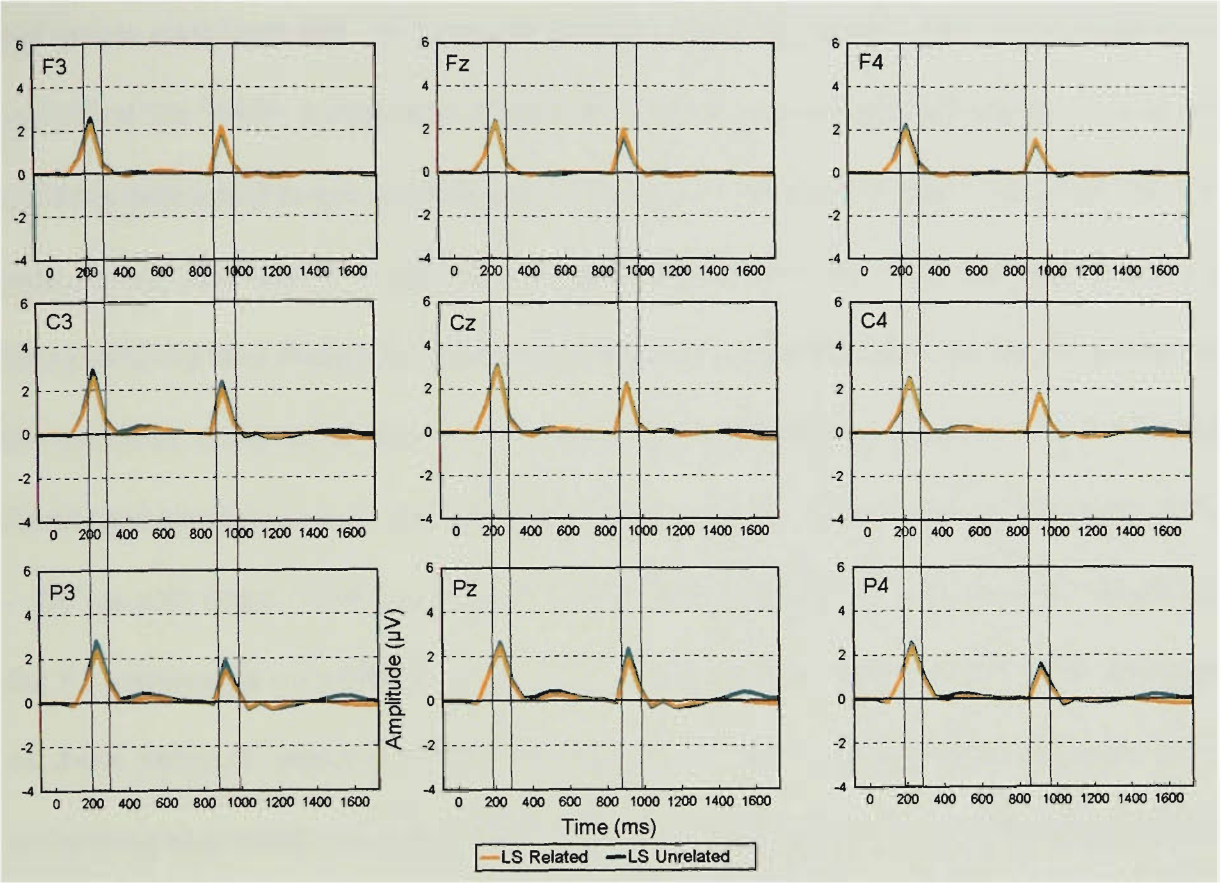


Figure 5.28. Grand average ERPs multiplied by Factor 5 (P2) of the rotated, rescaled component matrix.

Factor 1 was a broadly-distributed slow negative wave, only apparent for targets, with a latency range from 475 ms post target onset to the end of the epoch examined (see Figure 5.24). This resembled the Slow Wave component identified in the previous analyses in terms of latency, topography and the eliciting stimulus. Factor 3 was a negativity maximal over the central-parietal regions of the scalp with a latency range of 525 - 700 ms post-prime onset (see Figure 5.25). It was consistent in relation to latency and topography with the CNV identified in previous analyses. The PCA clearly indicated that the other components associated with prime processing vary across experimental variables, subjects, and topography in a way similar to those associated with target processing. This is illustrated by a single factor displaying a component peak for both prime and target, encompassing a similar latency range after stimulus onset. This occurred for Factors 2, 4 and 5. Factor 2 was a central parietal negativity with peak latency between 300 - 525 ms

post-prime onset and 300 - 475 ms post target onset (see Figure 5.23). This Factor closely resembled the N400 component identified in relation to target processing in Analysis 1 and both prime and target processing in Analysis 2. Factor 4 displayed a positivity with a peak latency between 75 - 200 ms post-prime onset and 50 - 200 ms post target onset. This positivity was distinctly parietal (see Figure 5.25) and resembled the P1 identified in the previous analyses in terms of latency and topography. Factor 5 was a broadly-distributed positive component with a peak latency 200 - 300 ms post-prime onset and 200 - 300 ms post target onset (see Figure 5.26). This positivity was consistent in profile with the P2 component identified in the previous analyses (see Figure 5.20). The segregation of these pairs of peaks together in each of the three components indicates that the underlying systematic variation across site and the effects of the remaining experimental variables is broadly similar for both prime and target. Hence, the underlying cognitive processes associated with the processing of the prime are not distinct from those used to process the target, at least as expressed in these components.

The P2a component identified in Analysis 1 was not evident in Analysis 3. It was hypothesised in the discussion of Analysis 2 that the P2a could in fact be the continuation of CNV into the target epoch. The disappearance of the P2a in Analysis 3 and the continuation of the CNV after initial target presentation supports the contention that the P2a was a continuation of the CNV elicited by the prime, and only emerged in Analysis 1 due to the base-line adjustment method used there.

The latency ranges of the components shown in Table 5.5 were used to determine mean amplitude estimates of each component, which were submitted to statistical analysis. The factors used in the ANOVAs were the same as in the previous analyses, with an additional

2 levels of word type (prime, target) for components other than CNV and Slow Wave.

5.9.3. ERP COMPONENT RESULTS

5.9.3.1. P1

Over both prime and target responses, the P1 was larger parietally than frontally, and this difference was larger in the right hemisphere (1.33 μV) than the left hemisphere (0.53 μV) [$F = 11.26$, $p < 0.01$].

5.9.3.2. P2

The P2 was larger parietally than frontally and this difference was larger for the mean of the left and right hemispheres (0.85 μV) than the midline (0.74 μV) for prime responses, with the effect reversed and smaller for target responses (0.01 μV and 0.55 μV respectively) [$F = 8.00$, $p < 0.05$]. P2 was also larger centrally than for the mean of the frontal and parietal sites and this difference was larger over the midline region (0.87 μV) than the mean of the left and right hemispheres (0.32 μV) for prime responses, with the effect smaller and reversed for target responses (0.18 μV and 0.41 μV respectively) [$F = 17.77$, $p < 0.001$]. Overall, the P2 was larger for prime responses, which displayed a vertex to parietal left topography; the smaller target responses were more equipotential.

5.9.3.3. N400

Across both prime and target responses, the N400 was larger centrally (0.84 μV) than for the mean of the frontal and parietal sites (1.09 μV) in the left hemisphere, with the effect reversed in the right hemisphere (0.97 μV and 0.72 μV respectively) [$F = 7.95$, $p < 0.05$]. N400 was larger centrally (0.11 μV) than for the mean of the frontal and parietal sites (0.76 μV) over the midline region, but almost equipotential for the mean of the left and

right hemispheres (0.90 μV and 0.91 μV respectively) [$F = 5.94$, $p < 0.05$].

The N400 was larger centrally (0.41 μV) than for the mean of the frontal and parietal sites (0.91 μV) for target responses, with the effect reversed and smaller for prime responses (0.86 μV and 0.80 μV) [$F = 9.66$, $p < 0.01$].

That is, over the entire scalp the N400 displayed a central left to vertex topography. Target responses displayed a centrally-distributed N400 relative to prime responses which were frontally distributed. No priming effects of any nature were obtained.

5.9.3.4. CNV

CNV was elicited only by primes. It was larger frontally than parietally and this difference was larger over the midline region (0.51 μV) than the mean of the left and right hemisphere (1.53 μV) [$F = 7.99$, $p < 0.05$]. That is, the CNV displayed a fronto-midline maximum.

5.9.3.5. SLOW WAVE

Only targets elicited the Slow Wave. It was more negative frontally than parietally and this difference was larger over the midline region (1.11 μV) compared with the mean of the left and right hemispheres (0.12 μV) [$F = 6.25$, $p < 0.05$]. It was also more negative centrally (-0.05 μV) than for the mean of the frontal and parietal sites (0.76 μV) over the midline but almost equipotential for the mean of the left and right hemispheres (0.47 μV and 0.46 μV respectively) [$F = 6.32$, $p < 0.05$].

Related targets elicited a more-negative slow wave (-0.04 μV) than unrelated targets

(1.61 μV) over the parietal region but responses were almost equipotential frontally (0.33 μV and 0.34 μV respectively) [$F = 10.63$, $p < 0.01$]. Overall, the slow wave displayed a fronto-central midline topography. It was larger for related responses than unrelated responses and this effect displayed a parietal maximum.

The Slow Wave peaking after the presentation of the target words was typical in terms of its latency but not necessarily its scalp distribution (Holcomb, 1988; McCallum, as cited in Desmedt, 1979).

5.9.3.6. SUMMARY

The CNV was elicited only by primes and displayed a fronto-midline topography. The P1 was similar to both primes and targets, and maximal parietally in the right hemisphere. P2 to primes was larger and displayed a vertex to left hemisphere maximum, while the smaller target P2s were equipotential over the scalp. The N400 in target responses was slightly larger and displayed a central topography, compared with the frontal topography of prime responses. No relatedness effects were significant for the N400 or earlier components. The Slow Wave was elicited only by targets and was larger parietally for related than unrelated targets.

5.10. OVERALL SUMMARY

Tables 5.6 and 5.7 summarise the findings from the three analyses in relation to the components identified, and their topography. Topography was not identified in Analysis 2 as this was exploratory and no analysis of variance was performed on the data.

Analysis 1 **Target** **epoch only**	**Analysis 2** **Using separate epochs** **for Prime and Target**		**Analysis 3** **Prime and Target within** **the one epoch**	
Target **(Latency ms)**	**Prime** **(Latency ms)**	**Target** **(Latency ms)**	**Prime** **(Latency ms)**	**Target** **(Latency ms)**
P1 (100-190)	P1 (110-180)	P1 (100-190)	P1 (75-200)	P1 (50-200)
P2a (190-300)	P2a (180-290)	CNV (0-100)		
P2 (190-260)	P2 (220-320)	P2 (190-300)	P2 (200-300)	P2 (200-300)
N400 (300-430)	N400 (320-460)	N400 (300-460)	N400 (300-525)	N400 (300-475)
Slow Wave (430-900)	CNV (460-700)	Slow Wave (460-1000)	CNV (525-700)	Slow Wave (475-1000)

Table 5.6. Summary of ERP components, and latency ranges relative to stimulus onset, identified in the three separate analyses for prime and target responses (where applicable).

Analysis 1			Analysis 3		
Target only Component Identified	**Topography**	**Relatedness Effects**	**Prime and Target Components Identified**	**Topography**	**Relatedness Effects**
P1	parietal right		P1	parietal right	
P2a	frontal midline		CNV	frontal midline	
P2	equipotential over scalp		P2	larger for prim responses (vertex to left hemisphere target responses more equipotential	
N400	fronto-central left to parietal midline		N400	larger for target responses centrally; prime responses displayed a frontal topography	
Slow Wave	left central-midline to parietal right	larger for related responses parietally	Slow Wave	fronto-central midline	larger for related responses parietally

Table 5.7. Summary of ERP components, topography and effects for Analysis 1 and Analysis 3.

The components identified using PCA across the three analyses are generally quite consistent. The observation that the CNV in Analysis 3 shares the same topography as the P2a identified in Analysis 1 supports the argument of Analysis 2 that the P2a was a

reflection of CNV resolution and emerged as an artefact of baseline-adjustment. There were some noticeable differences in latency (see Table 5.6) and topography (see Table 5.7) between Analysis 1 and 3. For target responses, P1 displayed a parietal right topography in Analysis 1 and in Analysis 3, and the P2 was similarly equipotential in both analyses. In contrast, the N400 component displayed a fronto-central left to parietal midline topography in the first analysis, but a central maximum in the third analysis. The Slow Wave displayed a left central-midline to parietal right topography in Analysis 1, but was maximal over the fronto-central midline in Analysis 3. However, target responses elicited a relatedness effect in both analyses for the Slow Wave, for which related responses were larger than unrelated responses parietally. The topographical differences that emerged (see Table 5.7) may have been due to the slight variations in latency ranges between the two analyses, as depicted in Table 5.6. Variations in terms of latency could result from artefact caused by baseline-adjustment, and the apparent variations in topography may have emerged due to analytical differences arising from the inclusion of an additional 2 levels of word type (prime, target) in some of the Analysis 3 ANOVAs.

5.11. CONCLUSIONS

This experiment was designed to replicate the study conducted by Kutas and Hillyard (1989). Their paradigm enabled the mechanisms of semantic priming and the organisation of semantic memory to be studied without drawing the subject's attention to the semantic processes being investigated. Kutas and Hillyard (1989), rather surprisingly, reported a priming effect on N400 amplitude using a non-semantic delayed letter-search task. These findings were unable to be replicated in this experiment. However, one aspect of their behavioural data was replicated - correct responses when the letter was present (904 ms) were faster than when it was absent (1061 ms). This was the only

behavioural effect reported by Kutas and Hillyard (1989). Also, the target PCA did not reveal a component with the characteristics of the P3, indicating that the delayed letter search task did eliminate component overlap between the N400 and P3, as was reported by Kutas and Hillyard (1989). Kutas and Hillyard (1989) described the delayed letter-search task as non-semantic. That is, the task was assumed to require simple processing, matching visual features of the target letter against the visual features of the letter strings. However, the N400 effect reported by Kutas and Hillyard (1989) and the current behavioural results showing that responses were faster for related (943 ms) than unrelated word pairs (970 ms), regardless of letter presence, suggests that linguistic information was extracted and influenced performance in the letter-search task. The fact that targets elicited an N400 suggests that lexical sources of information were activated (Ziegler, Besson, Jacobs, Nazir, & Carr, 1997). This is supported by the priming effect on Slow Wave amplitude, which was larger for related than unrelated targets parietally. The Slow Wave is said to reflect retrieval from long-term memory and the parietal topography is consistent with the slow wave reported by Rösler, Heil and Glowalla (1993). Lang et al. (1989) suggested that the distribution of the Slow Wave is often over the cortical structures used to perform the particular task.

Overall, the lack of an N400 relatedness effect probably resulted from the task not drawing the subject's attention explicitly to the semantic information. This is compatible with previous findings showing that the magnitude of the priming effect on N400 amplitude is influenced by the extent to which the task encourages subjects to attend and utilize semantic information (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Deacon, Breton, Ritter, & Vaughan, 1991; Kellenbach & Michie, 1996; Rugg, Furda, & Lorist, 1988).

The lack of a priming effect on N400 amplitude for target responses in the delayed letter search task suggests that the cognitive process underlying the N400 effect is a controlled process, because a truly automatic process would not be affected by the nature of the task (Bentin, Kutas, & Hillyard, 1993; Brown & Hagoort, 1993, Chwilla, Brown, & Hagoort, 1995, Chwilla, Hagoort, & Brown, 1998, Kellenbach & Michie, 1996). It is therefore concluded that the priming effect on N400 reflects post-lexical priming mechanisms, such as semantic-matching/integration, and not lexical-level spreading activation.

The lack of a priming effect on N400 amplitude in all analyses of the current experiment is assumed to be the result of activation being task dependent. That is, optimal task performance may have required attention to be focused at the word (orthographic) and letter content level of processing as opposed to the lexico-semantic level (Ziegler, Besson, Jacobs, Nazir, & Carr 1997; Stolz & Besner, 1996). In the interactive activation framework this is conceptualised as 'set'.

The notion of 'set' has been described as the top-down influence on perception/behaviour (Neisser, 1967; Stolz & Besner, 1996). Henderson (as cited in Coltheart, 1987) described the top-down influence as the ability of an individual to control performance by drawing attention to different levels of representation in the network model, thus altering the distribution of activation across the network by biasing the gain between levels.

The task used in this experiment required that letter search be performed on the prime and target, and the 'system' may have been biased by the set adopted to interpret patterns of activation at the word and letter level. In this account, activation does not automatically flow to the semantic level, as is commonly assumed (Neely, 1977). It has been postulated

that the blocking of activation from the semantic level is strongly associated with the experimental context and is not an inevitable result of letter search *per se* (Henik et al., 1994; Stolz & Besner, 1996).

In the context of the Interactive Activation framework proposed by Stolz and Besner (1996), the flow of activation could have been as follows: Prime words activated the component letters at the letter level, and activation then spread to the appropriate word-level representations. The blocking of activation due to the set adopted prevented activation flowing to the semantic level, eliminating priming. Rather, activation was directed top-down back to the letter level. Subsequent presentation of the target resulted in the same path of activation.

However, the results do not fully support this scenario. The Slow Wave only occurred in target responses, and these responses demonstrated a relatedness effect. That is, targets elicited a larger Slow Wave to related than unrelated words, suggesting that semantic attributes were activated to some extent. Behavioural responses also displayed a priming effect, in that responses were faster for related than unrelated word pairs. A possible alternative to the scenario offered above is that the prime words activated the component letters at the letter level, activation then spread to the appropriate word-level representations and flowed through to the semantic level, where associates were activated. Activation then flowed top-down, activating the word-level representations of the prime and associates; activation then spread to the component letters. The presentation of the associated target then required less activation for subsequent recognition. This interpretation fits in well with the task because top-down processing bolsters target activation at the word and letter levels.

Although task demands focus attention at the letter level, lexical activation resulted in semantic activation that spread to related lexical entries. Multiple sources of linguistic information were activated, including semantic information, but the focusing of attention on the orthography and letter content means that the information may have been used in a manner not easily revealed. Carr and Posner (1995) suggested that the prestriate visual word form system is responsible for the orthographic representation of visual features. This representation is then transmitted to the temporal and prefrontal areas for lexical and semantic analysis. The processing of lexical information may be reflected in the N400 elicited by both primes and targets, which displayed a frontal and central distribution respectively. This suggests that the cognitive operation underlying the N400 component itself, not the N400 relatedness effect, may be an automatic process of lexical access. However, the difference in the topography between prime and target responses implies a variation in processing even though the components are the same. Also the topography is inconsistent with the PET experiment conducted by Peterson et al. (1990) which displayed a left hemisphere medial extrastriate cortex topography for words and pseudowords, but not illegal consonant strings. They suggested that this region was associated with the processing of the visual word form. The parietal topography of the priming effect on Slow Wave amplitude may reflect the use of semantic information to bolster orthographic and/or letter-level activation.

The novel contribution of this experiment was the statistical analysis used in Analysis 3, which was designed to examine whether the processing associated with prime words was similar to that for target words, particularly in relation to the traditional N400 latency range (approximately 300 ms to 450 ms). The PCA of the voltage x time function spanning the prime and target extracted single factors with a component peak occurring

for both prime and target over a similar time frame after stimulus onset (Factors 2, 4 and 5). As noted earlier, this implies that some of the underlying cognitive processes associated with prime processing are not distinct from those used to process the target. Therefore, the component associated with processing over the N400 latency range for both prime and target requires one label. It has been suggested previously that the N400 is in fact an N2 (Ritter et al., 1983; Ritter et al., 1984; Polich, 1985). According to Ritter et al. (1983), the N2 reflects the stimulus-classification stage of processing regardless of the type of stimulus. Alternatively, Näätänen and Picton (as cited in McCallum, Zappoli, & Denoth, 1986) have suggested that the N400 is one of a group of distinct N2 components that can contribute to the overall N2 deflection. Accordingly, the components extracted in Factor 2 will be given the nomenclature of N400 and considered to be one of a group of N2 components that can contribute to the overall N2 deflection.

The prime and the target each elicited an N400, but the literature tends to focus only on N400 processing associated with the target. There is growing support to suggest that the cognitive process underlying the target N400 effect is a controlled process of semantic integration. The integration hypothesis suggests that the amplitude of the N400 reflects the ease with which sources of knowledge (e.g. lexical, syntactic, semantic) are used to construct a representation of the integrated discourse (Silva-Pereyra et al., 1999). However, an N400 component was elicited by the prime and target in the absence of an N400 relatedness effect, so what type of processing does the N400 reflect in this instance? Ziegler et al. (1997) described the processing of a single stimulus in a delayed letter-search task which used words, pseudowords (orthographically and phonologically legal letter strings) and nonwords (strings of consonants that were orthographically and phonologically illegal). The words and pseudowords elicited an N400, whereas the

nonwords did not. In the case of the words, this was suggested to reflect activation of orthographic, phonological and lexical sources of information; for the pseudowords, orthographic, phonological and partial lexical information may have been activated; but for nonwords, none of the multiple sources of linguistic information could be activated. Ziegler et al. (1997) suggested that the N400 may reflect lexical activation. The process of lexical access is described as automatic and involves computing a form representation onto corresponding entries in the mental lexicon. Any task that contains information relevant to the mental lexicon tends to elicit an N400. Holcomb (1988) suggested that the N400 reflects automatic as well as controlled processes. Thus the N400 component may reflect an automatic process related to lexical access, whilst the N400 relatedness effect could reflect a controlled process of semantic integration.

The only component that was distinct for prime processing was the slow negativity developing after presentation of the prime words. This was consistent with the contingent negative variation in terms of its latency and frontal-midline topography (Hillyard, as cited in McCallum & Knott, 1973; Holcomb, 1988; McCallum, as cited in Desmedt, 1979; Rohrbaugh & Gaillard, as cited in Gaillard & Ritter, 1983). The CNV is assumed to reflect cognitive processing associated with the preparation or anticipation of a stimulus event, which is consistent with the current task (Donchin, Gerbrandt, Leifer, & Tucker, 1972; Hillyard, as cited in McCallum & Knott, 1973; Holcomb, 1988; McCallum, as cited in Desmedt, 1979; Rohrbaugh & Gaillard, as cited in Gaillard & Ritter, 1983).

The major outcome of the study was the inability to replicate the priming effect on N400 in a delayed letter search task reported by Kutas and Hillyard (1989). The current experiment focused attention on orthography and letter content, and such tasks are not

commonly associated with priming effects (Friedrich, Henik, & Tzelgov, 1991; Henik, Friedrich, & Kellog, 1983; Henik, Friedrich, Tzelgov, & Tramer, 1994; Stoltz & Besner, 1996). However, the priming effect on Slow Wave amplitude and reaction time implies that linguistic information was used to perform the task. The findings strongly support previous work which has concluded that the priming effect on N400 amplitude elicited by the target is not enhanced in tasks which do not encourage the integration of semantic information (Bentin, Kutas, & Hillyard, 1993; Brown & Hagoort, 1993, Chwilla, Brown, & Hagoort, 1995, Chwilla, Hagoort, & Brown, 1998, Kellenbach & Michie, 1996). The main methodological contribution of this experiment was the novel use of PCA to show that the underlying cognitive processes associated with processing the prime are similar to those used to process the target.

Multitasking may provide a means of extending the statistical approach developed in this experiment. The multitasking approach enables comparison of performance across tasks which use similar underlying basic processes but differ in relation to task-specific processing (e.g. Ziegler, Besson, Jacobs, Nazir, & Carr, 1997). A suitable multitask would be one in which the extent of semantic analysis is varied. Also, the application of PCA across the voltage x time function spanning both prime and target provides a promising direction for future studies.

CHAPTER 6

EXPERIMENT 2

6.1. INTRODUCTION

The aim of the current experiment was to adopt a multitasking approach, varying the extent of semantic analysis. The PCA across the voltage x time function spanning both prime and target was again used to probe the ERP components associated with processing both the prime and target words. Multitasking was used so that performance across tasks could be compared. These tasks were assumed to be similar in underlying basic reading processes but to differ in relation to task-specific processing. In one task subjects were presented with a list of words which they were required to read silently. In another task, they were presented with word pairs and required to determine whether the target word was related to the preceding prime word. The tasks were chosen based on previous studies which have reported larger priming effects when subjects actively attend to the semantic aspects of the prime (Henik, Friedrich, & Kellogg, 1983; Kellenbach & Michie, 1996; Smith, 1979; Smith, Theodor, & Franklin, 1983). It was assumed that the two tasks involve different levels of processing because of the way attention is initially directed by the tasks. That is, the silent reading of word pairs does not necessitate analysis of semantic features. In contrast, the relatedness-judgement task requires explicit attention to the semantic relationship between the word pairs to make a decision.

A key assumption in the Stolz and Besner (1996) model of word recognition is that subjects are able to adopt task-specific top-down processes that bias the focus of attention

to different levels of the model, which in turn modulates the flow of activation. Task demands associated with the relatedness-judgement task are assumed to require semantic processing and to bias the system to interpret patterns of activation at the semantic level. On the other hand, it is assumed that the silent-reading task can be performed using bottom-up processing. The task demands associated with silent reading are less likely to require subjects to adopt top-down processes to modulate the flow of activation.

Since N400 has been accepted as an index of semantic processing of target words, a larger priming effect on N400 amplitude was anticipated for target words in the relatedness-judgement task than the silent-reading task. A priming effect on reaction time (RT) was also expected for the former task. The experiment attempted to determine the locus of the priming effect on N400 in relation to lexical-access and post-lexical processes. If the priming effects are obtained as anticipated above, this would support a post-lexical semantic-matching/integration account of the N400 effect, and imply that it reflects attentional processing, because a truly automatic process such as spreading activation would not be affected by changing the level of processing. In contrast, if there are no task differences in the N400 effect, then the locus of the effect will be difficult to determine in relation to lexical-access and post-lexical processes because the effect could emerge due to either process.

Another issue in relation to target processing is whether the elicited N400 reflects cognitive activity that is independent of the P3. Polich (1985) reported a priming effect on the N400 and P3 in a task requiring an overt semantic discrimination. This effect has also been reported in other studies (Bentin et al., 1985; Holcomb, 1986; Boddy, 1986). Boddy (1986) used a lexical-decision task and reported a more fronto-central N400 effect,

which was greater over the left hemisphere. It was suggested that the N400 topography appears more frontal due to the posterior distribution of the overlapping P3. This has made it difficult to distinguish whether the priming effect on N400 amplitude is independent of that on P3 amplitude. In order to establish the priming effect on N400 amplitude independently of P3, experiments have been designed which do not require a response to relevant stimuli. Such experiments have reported an N400 effect that was not followed by a P3 component, establishing the independence of the priming effect on N400 amplitude (Kutas & Hillyard, 1980, 1983, 1984; Rugg, 1987).

The implications for the current experiment are that the relatedness judgement task was expected to elicit a priming effect on N400 and P3 amplitudes, however it would be difficult to determine whether the N400 priming effect occurs independently or is due to component overlap with P3. Any N400 elicited in the silent-reading task should be unconfounded by component overlap with the P3 because that task does not require an overt response and is not expected to elicit a P3 component. Hence any priming effect on N400 amplitude in the silent-reading task would imply that the priming effect occurs independently of P3.

The contingent negative variation (CNV) has been correlated behaviourally with event anticipation. It was expected to be elicited by prime words in anticipation of target words and to display a fronto-midline topography as reported in Experiment 1 (Birbaumer, Elbert, Canavan, & Rockstroh, 1990; Holcomb, 1988; Kellenbach & Michie, 1996; McCallum, as cited in Desmedt, 1979). Experiment 1 established that the CNV extended beyond the onset of the target, so that determining its latency range from an epoch which encapsulates both prime and target responses allowed a more complete representation of

what was occurring.

As shown in Experiment 1, a Slow Wave was only elicited by target words, and it displayed a relatedness effect with a parietal distribution. It is therefore anticipated that a Slow Wave will be elicited by target words in the current experiment, but it is difficult to predict if the relatedness effect will be elicited again. Experiments using concept formation have shown that the retrieval of information stored in long-term memory is associated with frontal negative Slow Wave potentials (Uhl, Lang, Lang, Kornhuber, & Deecke, 1990). Rösler, Heil and Glowalla (1993) concluded that the retrieval of different contents, stored permanently in an associative network, results in distinct strategies when conclusions about these contents are required, and this is reflected in the topographic differences over the frontal and parietal sites. They showed that the Slow Wave was associated with a frontal distribution when the task required general scanning of long-term memory, whereas specific retrieval was associated with a parietal distribution.

Both tasks in the current experiment were assumed to be associated with memory retrieval processes. Therefore, it was anticipated that a frontal cortical Slow Wave could be elicited in the silent-reading task if general scanning of long-term memory were to occur. It was expected that the relatedness-judgement task would require greater effort than the silent-reading task, in relation to the retrieval of semantic characteristics of the prime and target from long-term memory, and would therefore elicit a larger Slow Wave. The relatedness-judgement task was assumed to require specific semantic information in order to perform the task and was therefore expected to elicit a parietally-distributed relatedness effect in the Slow Wave, similar to that elicited in Experiment 1.

Through the use of PCA, Experiment 1 established that the negativity elicited by both prime and target words in the traditional N400 latency range (approximately 300 ms to 450 ms) reflect the same component. This component was given the nomenclature of N400 based on the work of Näätänen and Picton (as cited in McCallum, Zappoli, & Denoth, 1986), who suggested that the N400 is one of a group of distinct N2 components that can contribute to the overall N2 deflection. By applying principal components analysis over the time span encompassing both the prime and target, the current study seeks to replicate the findings of Experiment 1, which showed that the prime and target words elicit similar components. If replicated, this would support the conclusion that the same underlying processes are used in the processing of both the prime and target.

6.2. METHOD

6.2.1. SUBJECTS

Twenty university students (15 females and 5 males) aged between 19 and 27 years (mean = 20.0 yrs) participated in the experiment as one means of satisfying a course requirement. All subjects spoke English as their first language and had normal or corrected-to-normal vision.

6.2.2. STIMULI AND DESIGN

One hundred and sixty semantically-associated word pairs (primes/targets) of 3-8 letters (mean = 5.2 letters) were selected from Postman and Keppel's (1970) word association norms of production. The pairs selected were either first- or second-choice associates. One hundred and sixty semantically-unrelated word pairs were also generated, matching the semantically-related word pairs on word length. Primes were also matched on word length.

The experiment consisted of a silent-reading and a relatedness-judgement task. Eighty semantically-associated word pairs and eighty unrelated word pairs were assigned to each condition. The stimuli were randomised, except that no more than three related or unrelated word pairs occurred consecutively and no prime was related to the preceding target.

The 160 primes and targets in each block were presented consecutively. Stimuli were presented foveally on a monitor, with each word exposed for 200 ms, with an inter-stimulus interval of 400 ms. The inter-trial interval was 2000 ms, during which a fixation point was presented. The viewing distance was 110 cm and the stimuli were presented in upper case letters 10 mm high and 5 mm wide. Reaction times (collected in the relatedness judgement task) were considered valid only if they occurred during the inter-trial interval and corresponded to the predetermined definition of a related or unrelated target.

6.2.3. ERP RECORDING

EEG activity was recorded from 9 scalp electrodes in an electrode cap. Electrode position was in accordance with the 10-20 system (Jasper, 1958) at frontal (Fz), central (Cz) and parietal (Pz) midline sites, and frontal (F3, F4), central (C3, C4) and parietal (P3, P4) lateral sites, with linked earlobes used as the reference. Vertical eye movement (VEOG) was monitored through electrodes above and below the right eye, and horizontal eye movement (HEOG) was monitored via a right to left canthal bipolar montage. The impedance at each electrode was less than 5 kOhm, and activity was amplified (EEG gain = 20,000; EOG gain = 5,000) with a bandpass of 0.01-35 Hz. EEG was continuously recorded at 256 Hz per channel and stored for offline analysis. From this, 2000 ms epochs

of EEG were taken from 100 ms before each prime.

6.2.4. PROCEDURE

Experimental trials were presented in two blocks of 160 word pairs. In one block, subjects were instructed to read the words silently as they appeared on the screen and were kept naïve about the semantic relationship between the word pairs. In the other block, subjects performed a relatedness-judgement task by pressing one of two laterally-positioned buttons as quickly and accurately as possible if they considered the target to be related to the prime, and the other if it was considered unrelated. The button assigned to each word type was counterbalanced across subjects. The silent-reading task preceded the relatedness-judgement task in order not to draw attention to the semantic relationship between the words in the pairs in the silent-reading task. Subjects were also instructed to minimize body and eye movements.

6.2.5. DATA ANALYSIS

For each site, average ERPs were calculated, and trials invalidated by excessive eye movement (>±100 μV) or behavioural response errors were excluded. The data collected from five of the twenty subjects was not utilised due to excessive eye movement. Principal components analysis (PCA) was used to examine the data because it provided an objective statistical method of selecting and defining the components, compared with the visual selection method, which is widely adopted but open to experimenter bias. In order to perform the PCA for the prime and target combined, every eighth point in the data set was selected (Coles, Gratton, Kramer, & Miller, as cited in Coles, Donchin, & Porges, 1986). PCA was carried out from 100 ms pre-prime onset to 1900 ms post-prime onset. All Factors whose eigenvalues exceeded unity were retained. The analysis consisted of 2

tasks x 2 word types x 2 relatedness levels x 9 electrodes x 15 subjects forming 1080 cases. SPSS-X V8 with varimax rotation of factors was used to perform the PCA on the covariance matrix. The method was chosen as a means of discriminating between components and establishing their latency ranges (Fabiani, Gratton, Karis, & Donchin, as cited in Acckles, Jennings, & Coles, 1987; Taylor, Smith, & Iron, 1990).

Before statistical analysis of components, mean amplitude measures were established at each site for each of the component latency ranges identified using PCA. The ERP data were normalized across scalp sites using the method described by McCarthy and Wood (1985). All data for each component were analysed using repeated measures ANOVAs and planned contrasts. There were 3 levels of a lateral factor (left, right and midline), 3 levels of a sagittal factor (frontal, central and parietal), 2 levels of word type (prime and target), 2 levels of task (silent-reading and relatedness-judgement), and 2 levels of relatedness (related and unrelated). Planned comparisons within the lateral factor compared left with right activity, and their mean with activity at the midline. Planned comparisons compared frontal with posterior activity, and their mean with central activity within the sagittal factor. Such planned comparisons allow optimal resolution of topographic effects, and their single degree of freedom F tests avoid the problems which may occur with non-sphericity of the variance-covariance matrix in repeated-measures designs. The only topographic effects or interactions reported are those which were significant for the raw data and remained so in the normalised data. All F tests had (1,14) degrees of freedom and the significance criterion was $p < 0.05$. The behavioural data from the relatedness-judgement task were analysed using a t-test on the 2 levels of relatedness.

6.3. RESULTS

The descriptors 'prime' and 'target' will be used for both tasks, but 'target' in the silent-reading task refers to the word following the 'prime' and completing a word pair.

6.3.1. BEHAVIOURAL DATA

In the relatedness-judgement task the mean reaction times of related targets were compared to those of unrelated targets in order to determine behavioural priming effects. Reaction times to related targets were significantly faster (559 ms, SD 147 ms) than to unrelated targets (734 ms, SD 131 ms) [$t(14) = -6.695$, $p < 0.001$], indicating that a facilitatory priming effect occurred in the related word pair condition.

6.3.2. ERPs

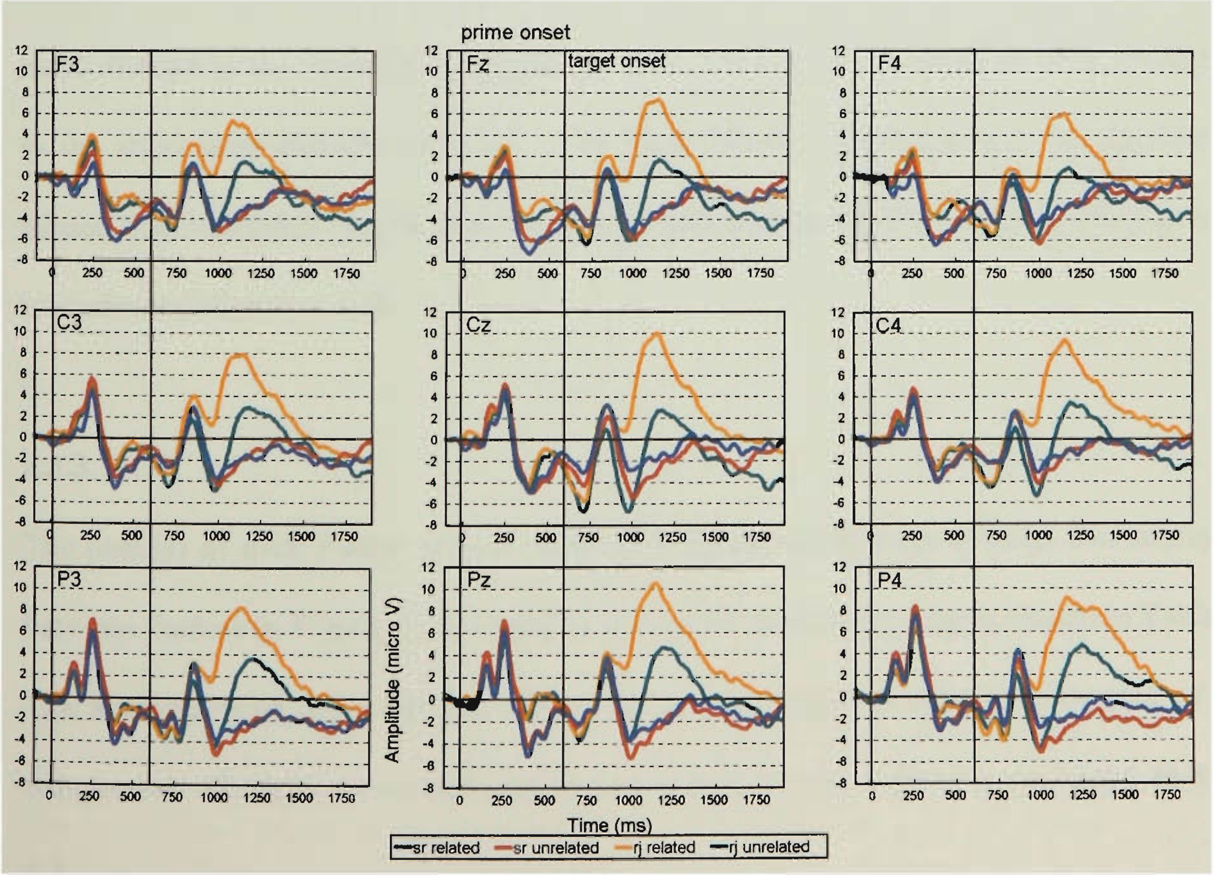


Figure 6.1. Grand average ERPs evoked by related and unrelated prime-target pairs in the silent-reading (sr) and relatedness-judgement tasks (rj).

As is apparent in Figure 6.1, a P1N1 complex was elicited by both primes and targets at parietal sites, where it preceded the P2, possibly causing a delay in its latency. A distinct P2 was evident for responses to primes and targets over the entire scalp, with a slight delay parietally as mentioned above, and responses appeared to be larger for related than unrelated target words, particularly over the frontal region. The N400 appeared over the entire scalp for both primes and targets. Primes appeared to elicit a larger N400 frontally and centro-parietally in the silent-reading task compared with the relatedness-judgement task. In the relatedness-judgement task, the N400 was larger for unrelated targets than related targets and this effect appeared to be maximal over the central and parietal regions. The N400 was followed by P3, which was most distinct in the relatedness-judgement task for primes and targets. The P3 was larger for responses to related than unrelated targets; this effect appeared to be maximal at the vertex whereas P3s to primes were equipotential. The CNV also appeared to be developing prior to the onset of the target word and was more distinct in the relatedness-judgement task, but the CNV was somewhat unclear due to the short inter-stimulus interval. The Slow Wave appeared larger for responses to related than unrelated targets over the central and parietal-midline regions, but only in the relatedness-judgement task.

6.3.3. PCA

The peak(s) of each Factor were identified and then component overlap was minimised between Factors in Figure 6.2 in order to determine the latency ranges shown in Table 6.1. The analyses used these latency ranges to compute mean amplitude estimates of each component. Table 6.1 also summarises the variance explained by each Factor in Figure 6.2.

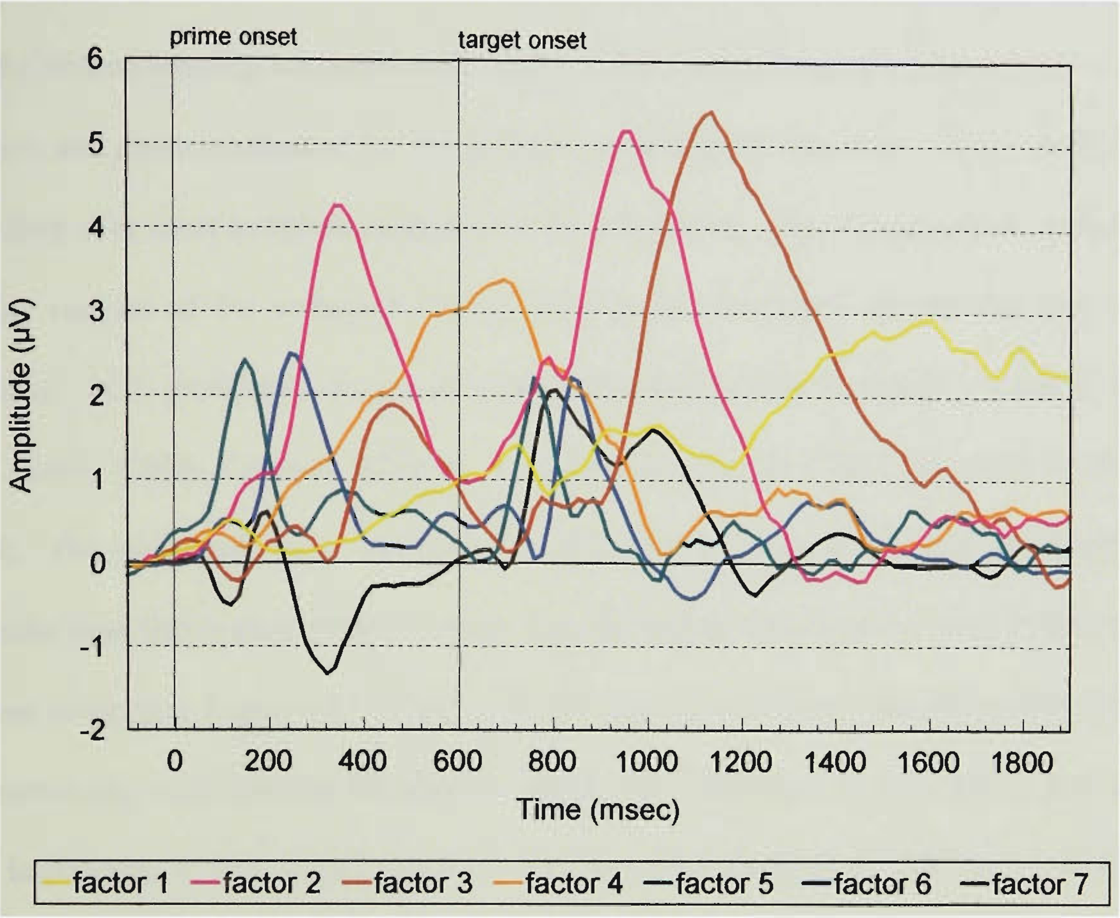


Figure 6.2. Factors extracted using PCA on prime and target responses across the whole epoch.

Factor	Component	% of Variance explained	Cumulative %	Latency ranges (ms) Prime	Latency ranges (ms) Target
Factor 1	Slow Wave	55.09	55.09		800 – 1300*
Factor 2	N400	14.35	69.44	290-415	300-450
Factor 3	P3	8.63	78.07	415 – 500	450 – 800
Factor 4	CNV	4.18	82.25	500 – 700*	
Factor 5	Unclear	2.76	85.01	------------	------------
Factor 6	P2	2.13	87.14	200 – 290	200 – 300
Factor 7	Unclear	1.99	89.13	------------	------------

Table 6.1. Variance carried by ERP components and their latency ranges identified for prime and target responses using PCA. *Note: The PCA for these components displayed a single peak over the indicated latency range. Factor 5 and Factor 7 were not analysed due to difficulty in identifying their component structure.

As noted in Experiment 1, the PCA illustrated in Figure 6.2 produced a typical outcome in that the slowest-varying component encompassed the largest region of the voltage by time function and hence accounted for the greatest percentage of variance. Faster components extending over short temporal ranges were then extracted. These components encompass smaller regions of the voltage by time function and therefore account for less of the variance. PCA produces orthogonal components that reflect systematic variation in the data matrix (Coles, Gratton, Kramer, & Miller, as cited in Coles, Donchin, & Porges, 1986). The component peak was generally found to occur for both prime and target over a similar time frame after stimulus onset (see for example Factors 2, 3 and 6) and within the one factor (see Figure 6.2). That is, the underlying systematic variation across site and the remaining experimental variables is similar for responses to both prime and target. The implication is that underlying cognitive processes associated with the processing of the prime are not distinct from those used to process the target. The variance of the factors determined using the PCA is also shown in Table 6.1.

An unusual finding was that the CNV accounted for less of the variance than the P3 and N400, which are considered to extend over a shorter temporal range. This could have been the result of temporal constraints placed on the CNV by the short ISI between stimuli, and the fact that it was apparent only following the prime.

The figures below depict the grand average ERPs multiplied by the rotated, rescaled component matrix for each factor, to investigate the topography of the components derived by the PCA. In these figures, the latency range associated with the component is shaded.

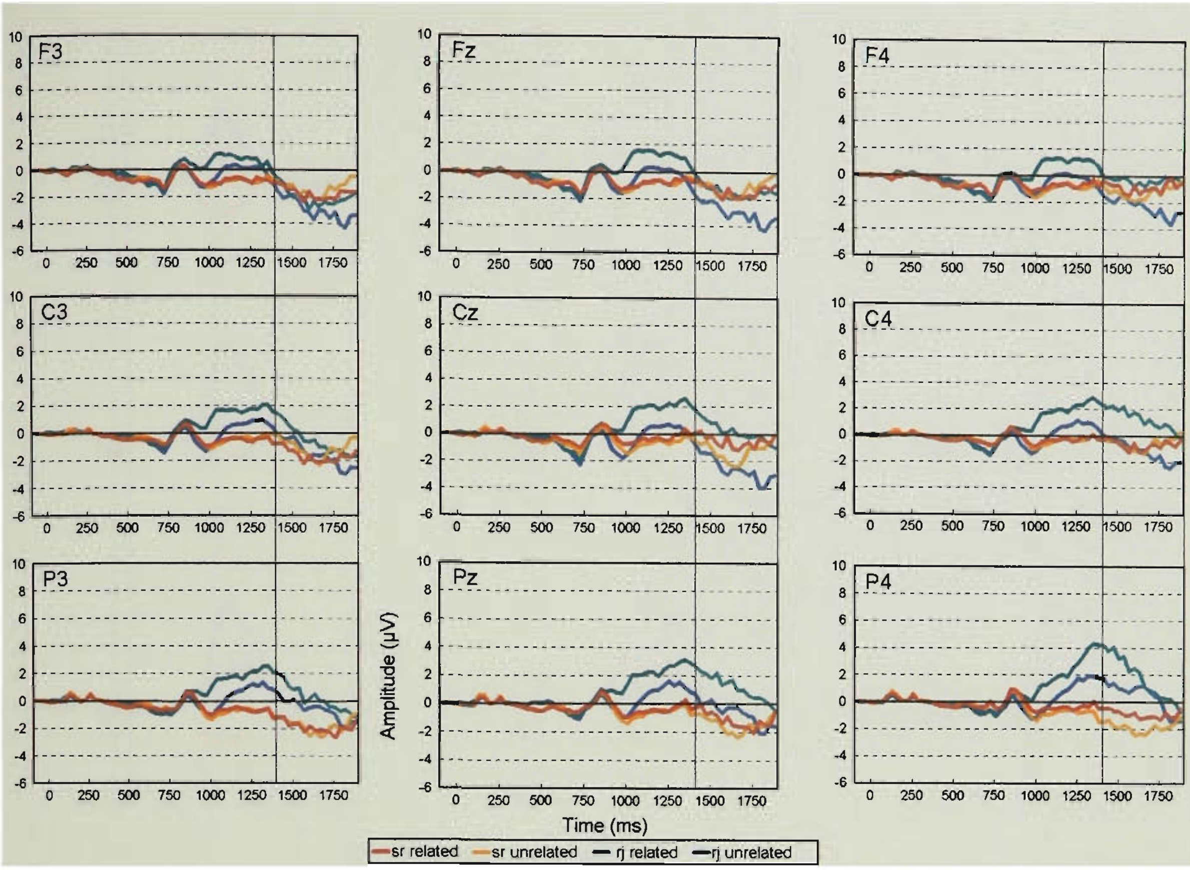


Figure 6.3. Grand average ERPs multiplied by Factor 1 (Slow Wave) of the rotated, rescaled component matrix.

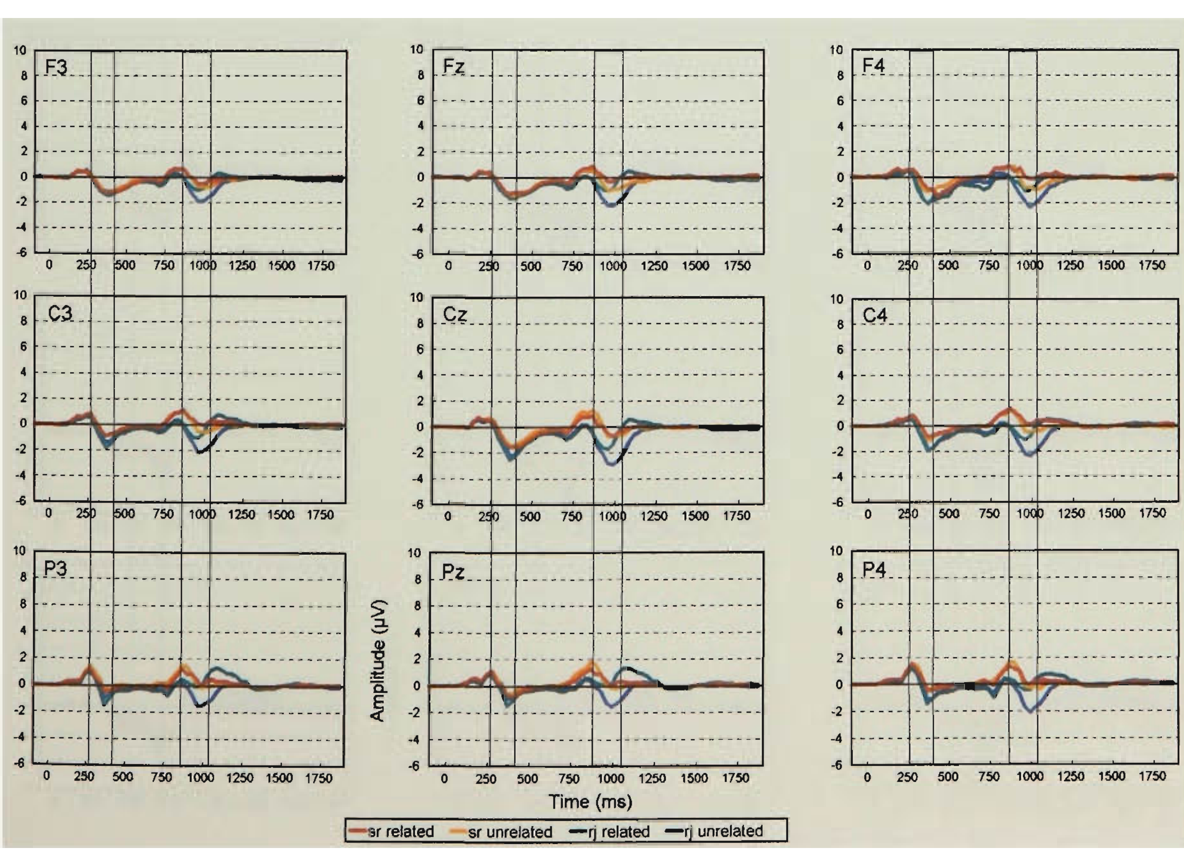


Figure 6.4. Grand average ERPs multiplied by Factor 2 (N400) of the rotated, rescaled component matrix.

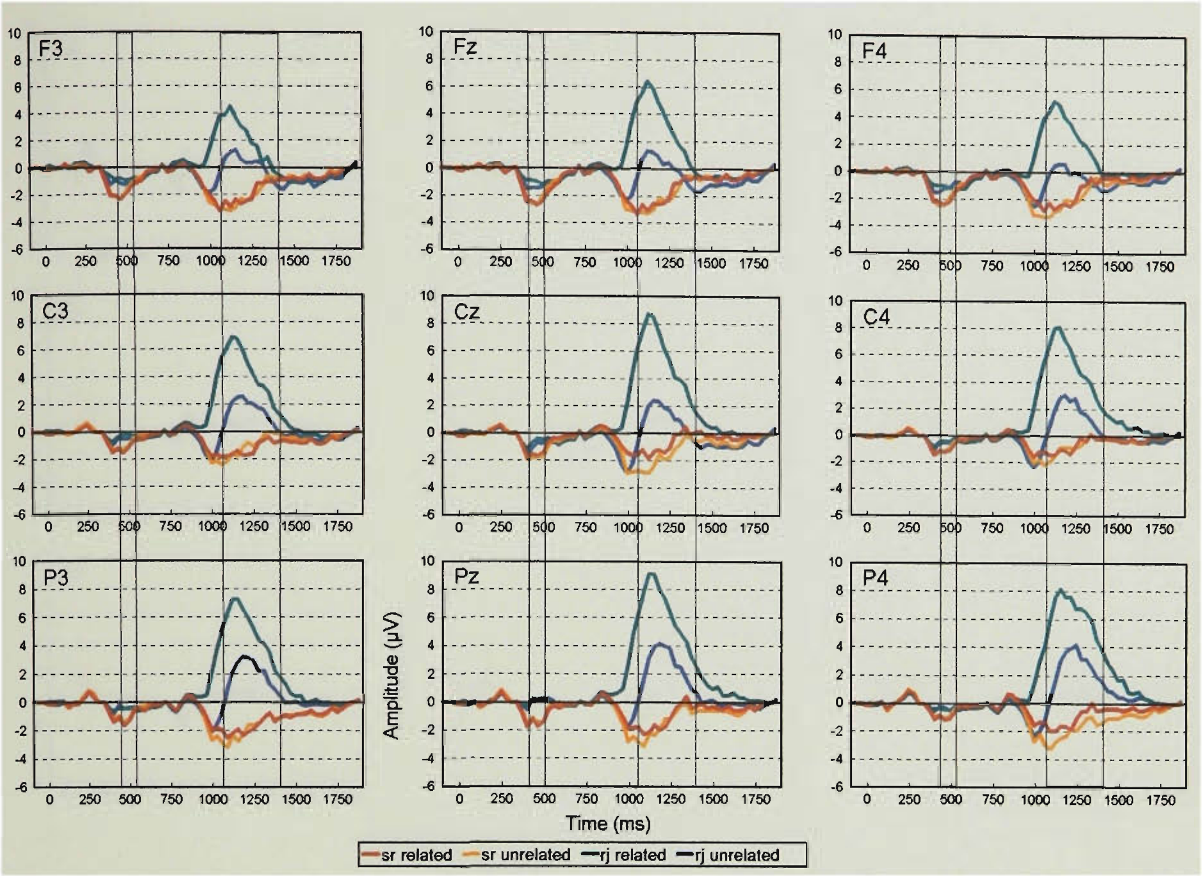


Figure 6.5. Grand average ERPs multiplied by Factor 3 (P3) of the rotated, rescaled component matrix.

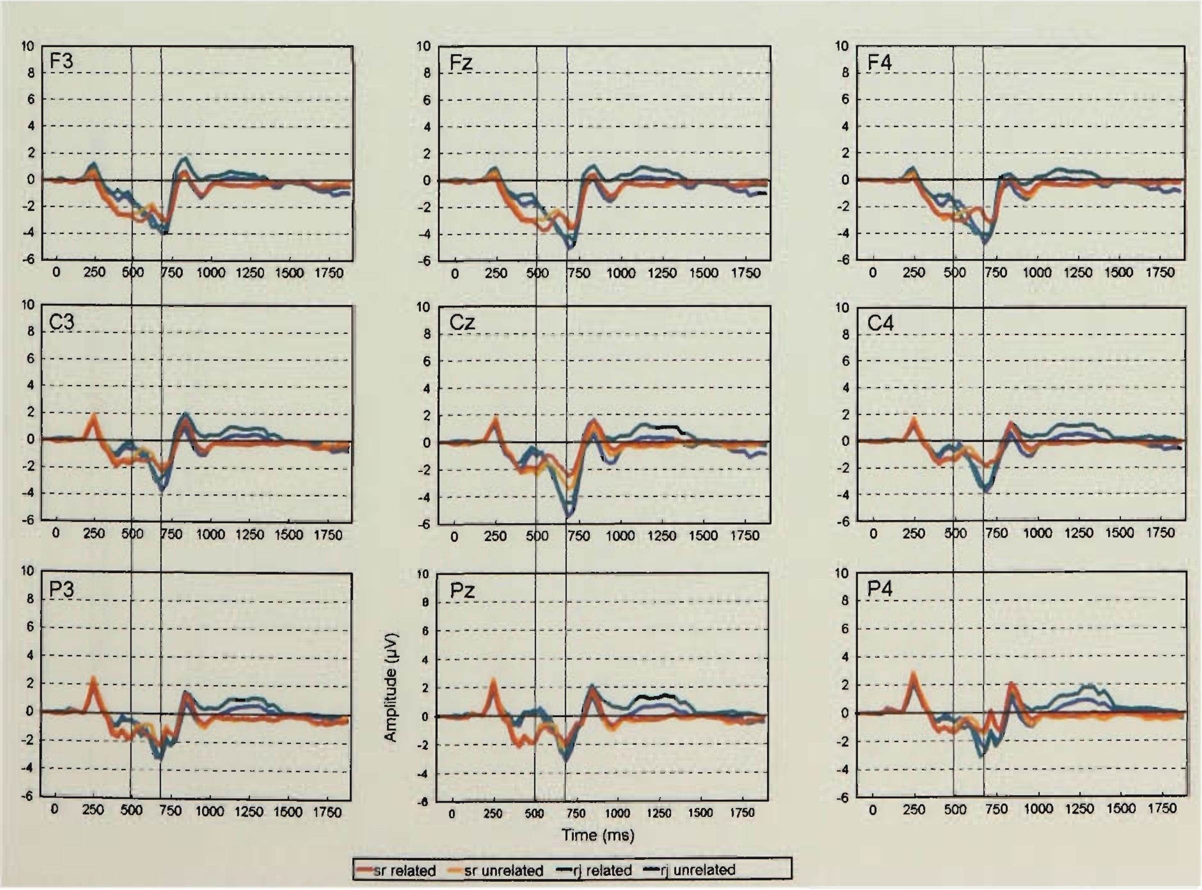


Figure 6.6. Grand average ERPs multiplied by Factor 4 (CNV) of the rotated, rescaled component matrix.

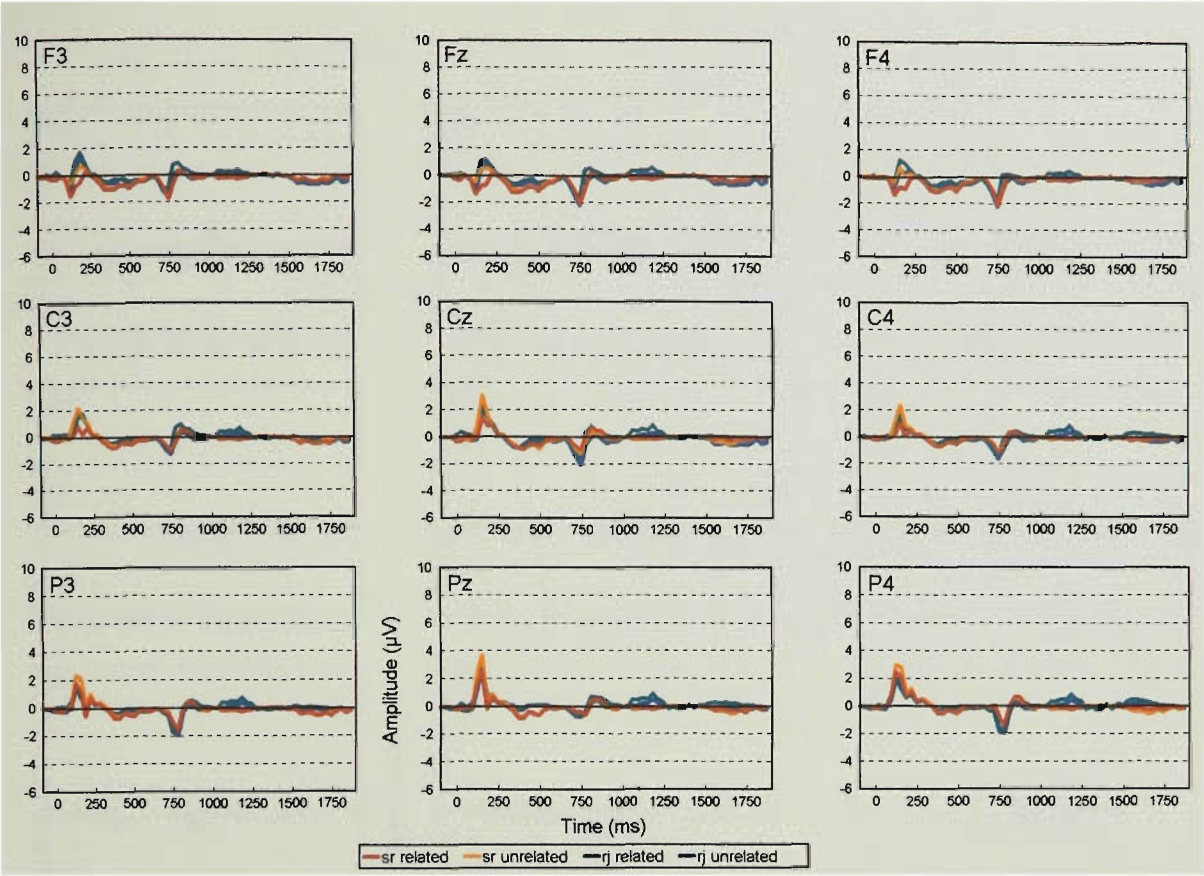


Figure 6.7. Grand average ERPs multiplied by Factor 5 of the rotated, rescaled component matrix.

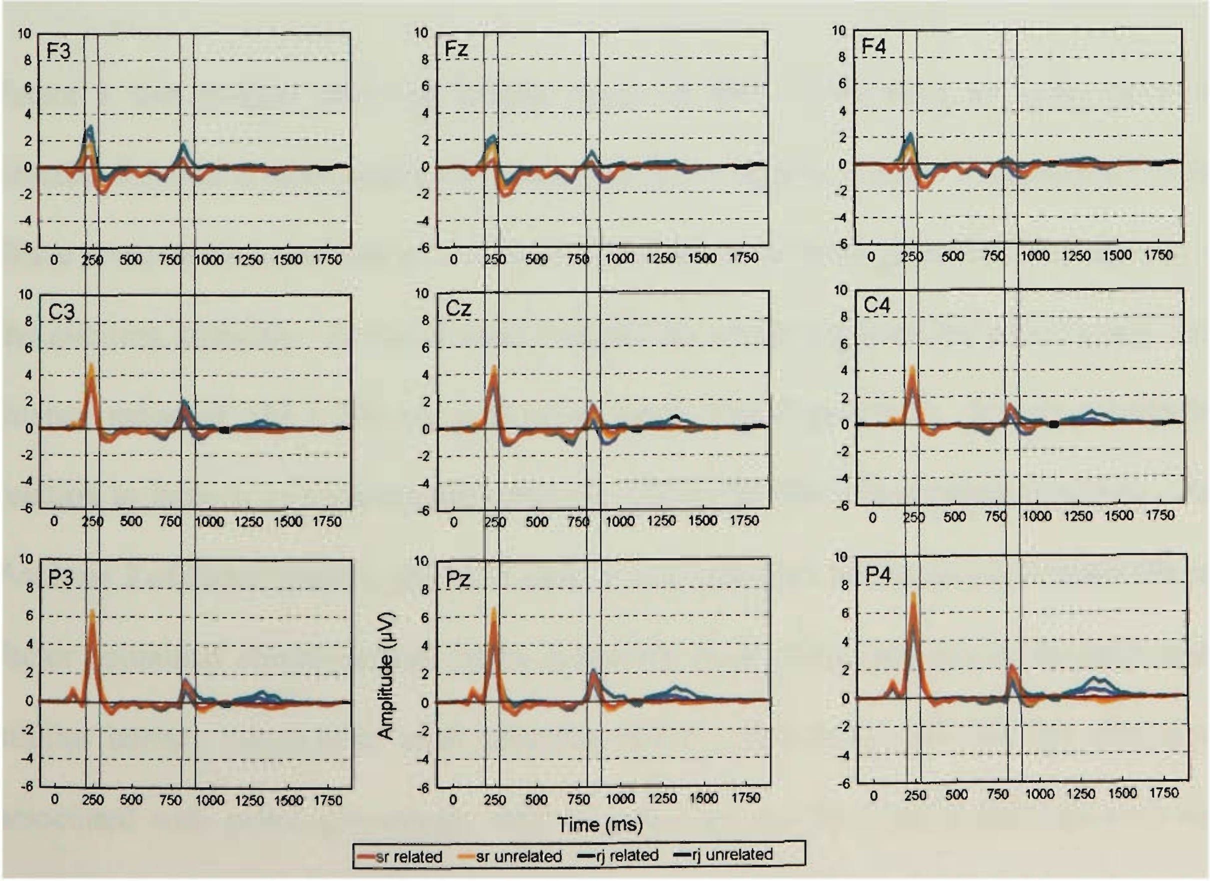


Figure 6.8. Grand average ERPs multiplied by Factor 6 (P2) of the rotated, rescaled component matrix.

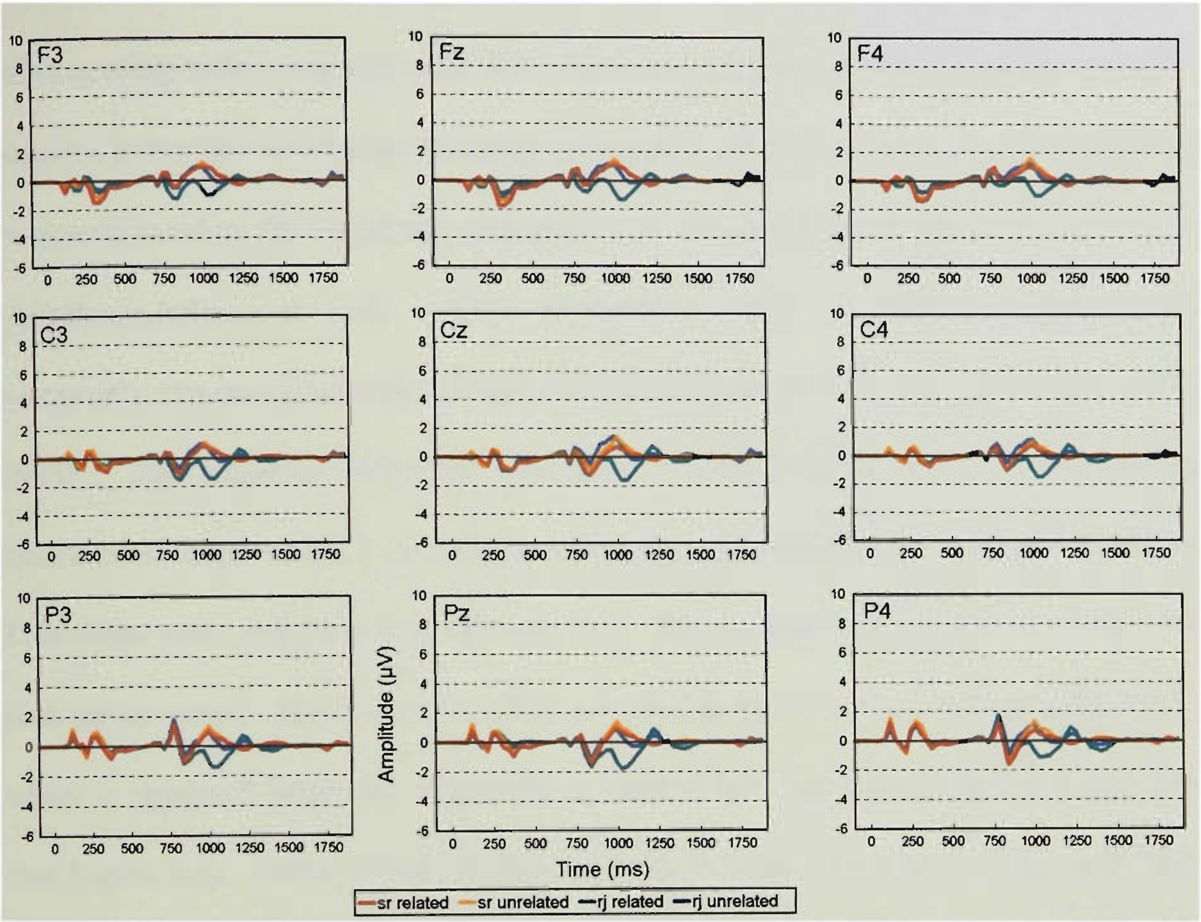


Figure 6.9. Grand average ERPs multiplied by Factor 7 of the rotated, rescaled component matrix.

Factor 1 was evident over the latency range of 800 - 1300 ms post target onset as a broadly distributed slow negativity peaking only for targets. Factor 1 resembled the Slow Wave component identified in the previous analyses in terms of latency, topography and the eliciting stimulus. Factor 4 was a negativity occurring over the entire scalp with a latency range of 525 - 700 ms post-prime onset (see Figure 6.3). It was consistent in relation to latency and topography with the CNV identified in previous analyses. As in Analysis 3 of Experiment 1, the PCA clearly indicated that for Factors 2, 3 and 6 the same factor contained corresponding peaks following both prime and target, encompassing a similar latency range after each stimulus onset. This indicated that the components associated with prime processing vary in a similar way to those associated with target processing, leading to their segregation together in each factor. Factor 2 included negative deflections with peak latencies between 290 - 415 ms post-prime onset and 300 -

450 ms post target onset (see Figure 6.4). This negativity appeared larger frontally in the silent-reading task compared with the relatedness-judgement task for prime words. The negative deflection was larger for target words preceded by a semantically-unrelated word compared to when the target was preceded by a semantically-related word, but only in the relatedness-judgement task. This relatedness effect displayed a central parietal topography commonly associated with the N400 component (Bentin, McCarthy, & Wood, 1985). The negative deflection described closely resembled the N400 component identified in Experiment 1 in relation to latency and topography. Factor 3 had positive deflections with peak latencies between 415 - 500 ms post prime onset and 450 - 800 ms post target onset. This positivity (P3) was dominant in the relatedness-judgement task where it appeared larger for responses to related than unrelated targets centro-parietally (see Figure 6.5). Factor 6 had positive deflections in the waveform with a peak latencies between 200 - 290 ms post prime onset and 200 - 300 ms post target onset. This positivity displayed a central parietal distribution and appeared to be larger for responses to primes (see Figure 6.8). When considering the Grand Average (see Figure 6.1.) it appeared that this positive deflection was larger for responses to related than unrelated targets over the frontal and central regions, which has been reported in relation to the P2 component (Garrett-Peters, Dun, Dun, & Andrasik, 1994; Raney, 1993).

6.3.4. ERP COMPONENTS

The following section will describe the components in the following order where appropriate: P2, N400, P3, CNV, Slow Wave. It should be noted that the CNV and Slow Wave components were only elicited by primes and targets respectively.

6.3.4.1. P2

P2 was larger parietally (3.28 μV) than frontally (0.97 μV) [$F = 10.00$, $p < 0.01$] and larger centrally (2.71 μV) than for the mean of the frontal and parietal sites (2.12 μV) [$F = 10.33$, $p < 0.01$]. It was also larger in the left hemisphere (2.54 μV) than the right hemisphere (2.07 μV) [$F = 31.70$, $p < 0.001$]. The parietal-frontal difference was larger for the right (3.13 μV) than the left hemisphere (1.34 μV) [$F = 16.12$, $p < 0.001$] and the central-frontal/parietal difference was larger for the left hemisphere (0.86 μV) compared with the right hemisphere (0.26 μV) [$F = 11.50$, $p < 0.01$]. Overall, P2 displayed a parietal-right to central-left topography.

The P2 elicited in the relatedness-judgement task was larger in the left (2.78 μV) than the right hemisphere (1.91 μV) but it was almost equipotential for the silent-reading task (2.32 μV versus 2.28 μV respectively) [$F = 13.52$, $p < 0.01$]. The parietal-frontal difference was larger for the silent-reading task (3.18 μV) than the relatedness-judgement task (1.45 μV) [$F = 8.12$, $p < 0.05$]. It was differentially larger for the mean of the left and right hemispheres (3.23 μV) than the midline (3.08 μV) in the silent-reading task, with the reverse in the relatedness-judgement task (1.23 μV versus 1.90 μV) [$F = 26.93$, $p < 0.001$]. It was larger centrally (2.85 μV) compared with the mean of the frontal and parietal sites (2.00 μV) in the silent-reading task relative to the relatedness-judgement task (2.57 μV versus 2.24 μV) [$F = 5.62$, $p < 0.05$]. Overall, the silent-reading task elicited a larger P2 than the relatedness-judgement task and it displayed a central to right parietal topography. The relatedness-judgement task produced a P2 topography that was maximal over the left hemisphere and the parietal midline region.

The P2 elicited by related word pairs (2.60 μV) was larger than to unrelated word pairs (2.10 μV) in the midline region than for the mean of the left and right hemispheres (2.46 μV and 2.15 μV, respectively) [$F = 6.84$, $p < 0.05$]. The difference between related and unrelated word pairs was larger centrally (0.58 μV) than the mean of the frontal and parietal sites (0.26 μV) [$F = 15.44$, $p < 0.01$]. It was also larger centrally (0.90 μV) than the mean of the frontal and parietal sites (0.31 μV) for the midline region compared with the mean of the left and right hemispheres (central: 0.41 μV and frontal/parietal: 0.26 μV) [$F = 4.78$, $p < 0.05$]. That is, the P2 was larger for related than unrelated responses and this effect displayed a vertex maximum.

Prime words elicited a larger P2 (3.26 μV) than target words (1.38 μV) [$F = 9.97$, $p < 0.01$]. The P2 was larger parietally than frontally and this difference was larger for prime words (3.16 μV) than target words (1.47 μV) [$F = 11.93$, $p < 0.01$]. For target words, the P2 was larger over the midline (1.60 μV) than the mean of the left and right hemispheres (1.27 μV), with the reverse for prime words (3.10 μV and 3.34 μV respectively) [$F = 20.05$, $p < 0.001$]. The frontal-parietal P2 difference was larger for the mean of the left and right hemispheres (3.34 μV) than the midline region (0.21 μV) for prime words, with the reverse for target words (1.11 μV and 2.19 μV respectively) [$F = 33.80$, $p < 0.001$]. For prime responses P2 was larger centrally (3.98 μV) than the mean of the frontal and parietal sites (3.25 μV) in the left hemisphere, with the reverse in the right hemisphere (3.03 μV and 3.26 μV respectively); for target responses, P2 (while smaller overall) was also larger centrally (2.24 μV) than in the mean of the frontal and parietal sites (1.25 μV) in the left relative to the right hemisphere (1.46 μV and 0.72 μV respectively). However, the central-frontal/parietal differences for target and prime

responses were more similar in the left (0.99 μV and 0.73 μV respectively) than in the right hemisphere (0.74 μV and 0.23 μV respectively) [$F = 15.06$, $p < 0.01$]. P2 for prime words was larger centrally (3.67 μV) than the mean of the frontal and parietal sites (2.81 μV) over the midline region compared to the mean of the left and right hemisphere (3.50 μV and 3.25 μV), with the reverse for target words (central midline: 1.88 μV and frontal/parietal midline: 1.47 μV, central left/right: 1.85 μV and frontal/parietal left/right: 0.98 μV) [$F = 54.39$, $p < 0.001$]. That is, P2 was larger in prime responses and displayed a parietal right, central midline to left topography. Target responses displayed a parietal midline to central left topography.

Over the entire scalp, the P2 elicited by related word pairs (2.97 μV) was larger than unrelated word pairs (1.74 μV) in the relatedness-judgement task, with the effect smaller and reversed in the silent-reading task (2.05 μV and 2.53 μV respectively) [$F = 6.63$, $p < 0.05$].

Across sites, the P2 elicited by related targets (1.89 μV) was larger than unrelated targets (0.85 μV) whereas the prime responses were more equipotential (3.13 μV and 3.42 μV respectively) [$F = 24.10$, $p < 0.001$]. The difference between related and unrelated word pairs was larger over the midline (1.31 μV) than the mean of the left and right hemispheres (0.95 μV) for target words and more equipotential for prime words (0.29 μV and 0.34 respectively) [$F = 15.32$, $p < 0.01$]. Overall, related responses showed a larger P2 than unrelated responses for target words only. The unrelated-related difference displayed a midline maximum for target words but was almost equipotential for prime responses across tasks.

The P2 elicited in the silent-reading task was larger parietally than frontally and the difference was larger for the mean of the left and right hemispheres (4.55 μV) than the midline (3.76 μV) for prime words, with the reverse for target words (1.90 μV and 2.40 μV respectively). In the relatedness-judgement task the P2 was larger parietally than frontally and the difference was larger for the mean of the left and right hemispheres (2.15 μV) than the midline (1.82 μV), with the reverse for target words (0.32 μV and 2.00 μV respectively) [$F = 8.80$, $p < 0.01$]. That is, the P2 elicited in the silent-reading task was larger parietally with a right bias in responses to primes relative to the responses to targets, which displayed a midline-parietal topography. This effect was similar but smaller in the relatedness-judgement task.

In the relatedness-judgement task the P2 elicited by related targets was larger than that to unrelated targets, and this difference was larger frontally than parietally in the left hemisphere (2.22 μV and 1.64 μV) relative to the right hemisphere (1.82 μV and 1.02 μV) whereas prime response differences were more equipotential (prime frontal left: 0.86 μV and prime parietal left: 0.30 μV, prime frontal right: 0.67 μV and prime parietal right: 0.06 μV respectively). In the silent-reading task the difference between related and unrelated word pairs was more equipotential for both primes (prime frontal left: 1.31 μV and prime parietal left: 1.32 μV, prime frontal right: 1.27 μV and prime parietal right: 0.89 μV respectively) and targets (target frontal left: 0.18 μV and target parietal left: 0.06 μV, target frontal right: 0.18 μV and target parietal right: 0.41 μV respectively) [$F = 9.64$, $p < 0.01$]. Overall, P2 was larger for related targets than unrelated targets in the relatedness-judgement task, and the difference displayed a frontal left maximum, whereas the difference for primes was far more equipotential. This difference was more equipotential for both primes and targets in the silent-reading task.

6.3.4.2. N400

The PCA extracted a component with peaks in the N400 latency range elicited by the prime (latency 290 ms to 415 ms) and target (latency 300 ms to 450 ms) within the one factor (Factor 3). As mentioned earlier, since these peaks occurred within the one factor, it implies that they vary in a similar manner and will be treated as the same component. This component resembles the N400 component identified in the first experiment and will be given the same nomenclature.

Across tasks, word type and relatedness, the N400 was larger in the midline region (-2.35 μV) than the mean of the left and right hemispheres (-1.81 μV) [$F = 12.05$, $p < 0.01$]. It was larger frontally (-3.29 μV) than parietally (-0.80 μV) [$F = 11.31$, $p < 0.01$] and particularly so in the right hemisphere (-3.39 μV versus -0.51 μV) relative to the left hemisphere (-2.89 μV versus -0.98 μV) [$F = 6.98$, $p < 0.05$]. That is, the N400 displayed a midline to right frontal topography.

Across sites, the N400 was smaller in the relatedness-judgement task (-1.13 μV) than in the silent-reading task (-2.85 μV) [$F = 9.05$, $p < 0.01$]. It was larger centrally (-1.33 μV) than the mean of the frontal and parietal sites (-1.03 μV) for the relatedness-judgement task, with the reverse for the silent-reading task (-3.10 μV and -2.41 μV respectively) [$F = 19.77$, $p=0.001$]. For the relatedness-judgement task, N400 was larger in the right hemisphere (-1.16 μV) than the left hemisphere (-0.86 μV), with the reverse in the silent-reading task (-2.39 μV versus -2.82 μV respectively) [$F = 11.31$, $p < 0.01$]. The N400 frontal-parietal difference was larger in the silent-reading task for the mean of the left and right hemispheres (2.94 μV) than the midline region (2.56 μV), with the reverse in the relatedness-judgement task (1.86 μV and 2.81 μV respectively) [$F = 33.11$, $p < 0.001$].

The N400 was larger centrally (-2.20 μV) than the mean of the frontal and parietal sites (-1.00 μV) over the midline region than the left/right hemispheres (-0.9 μV and -1.1 μV respectively) for the relatedness-judgement task, with the reverse in the silent-reading task (midline: -2.85 μV and -3.60 μV, left/right: -2.18 μV and -2.82 μV) [$F = 7.32$, $p < 0.05$]. Overall, the N400 displayed a frontal midline maximum in the silent-reading task but was substantially reduced overall in the relatedness-judgement task, where it displayed a fronto-central midline to right-frontal maximum.

Over the entire scalp, the N400 was larger for unrelated words (-2.78 μV) than related words (-1.20 μV) [$F = 13.00$, $p < 0.01$]. This difference was larger over the midline region (1.84 μV) than the mean of the left and right hemispheres (1.45 μV) [$F = 16.14$, $p < 0.001$]. The difference was also larger centrally (2.39 μV) than the mean of the frontal and parietal sites (1.58 μV) for the midline region compared with the mean of the left and right hemispheres (1.56 μV and 1.39 μV respectively) [$F = 7.13$, $p < 0.05$]. That is, the difference between related and unrelated word pairs was maximal over the vertex.

This difference was much larger in the relatedness-judgement task (3.26 μV) than the silent-reading task (0.10 μV) [$F = 21.76$, $p < 0.001$]. It was larger in the left hemisphere (3.12 μV) than the right hemisphere (2.96 μV) for the relatedness-judgement task compared with the silent-reading task (0.44 μV versus 0.15 μV respectively) [$F = 8.23$, $p < 0.05$]. It was similarly differentially larger over the midline region (3.70 μV) than the mean of the left and right hemispheres (3.04 μV) for the relatedness-judgement task but not the silent-reading task (0.01 μV and 0.15 μV respectively) [$F = 10.56$, $p < 0.01$]. The difference between related and unrelated word pairs was larger centrally (3.72 μV) than

the mean of the frontal and parietal sites (3.04 μV) for the relatedness-judgement task but not the silent-reading task (0.05 μV and 0.12 μV respectively) [$F = 8.5$, $p < 0.05$]. The difference was larger centrally (4.20 μV) than the mean of the frontal and parietal sites (3.48 μV) for the midline region compared with the mean of the left and right hemispheres (3.48 μV and 2.83 μV respectively) for the relatedness-judgement task relative to the silent-reading task (midline: 0.56 μV and 0.32 μV, left/right: 0.37 μV and 0.04 μV respectively) [$F = 12.31$, $p < 0.01$]. Overall, the difference between related and unrelated word pairs had a strong vertex maximum in the relatedness-judgement task and was more equipotential, but almost absent, in the silent-reading task.

The N400 elicited by prime words was larger in the left (-1.98 μV) than the right hemisphere (-1.64 μV), with the reverse for target words (-1.69 μV and -1.91 μV respectively) [$F = 20.78$, $p < 0.001$]. It was also relatively larger over the midline region (-2.78 μV) than the mean of the left and right hemispheres (-1.81 μV) for prime words compared with target words (-1.91 μV versus -1.80 μV respectively) [$F = 78.86$, $p < 0.001$]. As noted above, the N400 was larger frontally than parietally and this difference was larger for prime words (3.30 μV) than target words (1.68 μV) [$F = 10.91$, $p < 0.01$]. It was also larger centrally than the mean of the frontal and parietal sites and this difference was also larger for prime words (0.41 μV) than target words (0.05 μV) [$F = 11.04$, $p < 0.01$]. The frontal-parietal difference for prime responses was almost equipotential for the mean of the left and right hemispheres (3.31 μV) compared with the midline (3.28 μV); for targets, the smaller frontal-parietal difference differed between the mean of the left and right hemispheres (1.47 μV) and the midline (2.09 μV) [$F = 20.05$, $p < 0.001$]. N400 was somewhat larger for the mean of the frontal and parietal regions

than the central region and the difference was larger in the right hemisphere (0.89 μV) than the left hemisphere (0.42 μV) for target words compared with prime words (0.13 μV versus 0.16 μV respectively) [$F = 7.56$, $p < 0.05$]. Overall, prime responses were somewhat larger and displayed a slightly-left, largely-frontal topography relative to target responses, which were more equipotential with a weak right frontal maximum.

Unrelated target words elicited a larger N400 (-3.64 μV) than related target words (0.16 μV) but this effect was not apparent in prime responses (-1.92 μV and -2.55 μV respectively) [$F = 88.16$, $p < 0.001$], indicating a priming effect on N400 amplitude only for target words. The priming effect was larger over the midline region (4.07 μV) than the mean of the left and right hemispheres (3.35 μV) for target words but not for prime words (0.38 μV versus 0.46 μV respectively) [$F = 27.44$, $p < 0.001$]. The priming effect was larger centrally (3.96 μV) than the mean of the frontal and parietal sites (3.41 μV) for target words but more equipotential for prime words (0.30 μV and 0.50 μV respectively) [$F = 10.16$, $p < 0.01$]. It was also larger centrally (4.83 μV) than the mean of the frontal and parietal sites (3.69 μV) over the midline region compared with the mean of the left and right hemispheres (3.52 μV and 3.26 μV respectively) for target words but not prime words (midline: 0.06 μV and 0.53 μV, mean of the left and right hemispheres: 0.41 μV and 0.48 μV respectively) [$F = 10.19$, $p < 0.01$]. That is, the responses to prime words preceding related and unrelated targets were almost equipotential, whereas the target responses displayed a priming effect with a strong vertex topography.

As noted earlier, responses were attenuated in the relatedness-judgement task compared with the silent-reading task. Although this affect was apparent in responses to primes

(relatedness-judgement: -1.58 μV versus silent reading: -2.69 μV), it was larger in the target responses (-0.68 μV for relatedness-judgement and -3.01 μV for silent reading) [F = 19.10, p < 0.001]. N400 was larger in the left than the right hemisphere for the silent-reading task and this difference was larger for prime words (0.58 μV) than target words (0.27 μV), in comparison with the relatedness-judgement task, where N400 was more equipotential (0.10 μV and 0.07 μV respectively) [F = 9.38, p < 0.01]. Overall, the amplitude of N400 elicited in the relatedness-judgement task was attenuated compared with the silent-reading task and this effect was larger for target than prime responses. In the silent-reading task, N400 amplitude was larger for prime responses in the left hemisphere, whereas this effect was almost equipotential in the relatedness-judgement task.

The priming effect on N400 amplitude (i.e., the reduction in N400 amplitude to related vs. unrelated words) was large for targets (6.25 μV) but not primes (0.27 μV) in the relatedness-judgement task, and small for both in the silent-reading task (0.93 μV and 1.14 μV respectively) [F = 48.68, p < 0.001]. It was also larger centrally (7.03 μV) than for the mean of the frontal and parietal sites (5.86 μV) for target words compared with prime words (0.41 μV and 0.21 μV respectively) in the relatedness-judgement task, but not in the silent-reading task (target: 0.90 μV and 0.96 μV, prime: 1.01 μV and 1.20 μV respectively) [F = 25.74, p < 0.001]. The priming effect was larger over the midline region (6.98 μV) than the mean of the left and right hemispheres (5.89 μV) for target words and almost equipotential for prime words (0.44 μV and 0.20 μV respectively) in the relatedness-judgment task compared with the silent-reading task, in which it was equipotential across prime (1.19 μV and 1.11 μV respectively) and target (1.17 μV and

0.82 μV respectively) [$F = 6.86$, $p < 0.05$]. For the relatedness-judgement task, the priming effect on N400 amplitude occurred for target words and was larger centrally (6.75 μV) than the mean of the frontal and parietal sites (5.40 μV) in the right compared to the left hemisphere (6.46 μV and 5.65 μV respectively) whereas prime words were much more equipotential (central right: 0.25 μV and frontal/parietal right: 0.02 μV, central left: 0.45 μV and frontal/parietal left: 0.25 μV). In contrast, for the silent-reading task, the priming effect was larger for the mean of the frontal and parietal sites (1.44 μV) than the central site (0.63 μV) in the right hemisphere compared with the left hemisphere (0.57 μV and 0.26 μV respectively) for target words, relative to prime words (frontal/parietal right: 0.86 μV and central right: 0.89, frontal/parietal left: 1.29 μV and central left: 1.48 μV respectively) [$F = 28.22$, $p < 0.001$]. Overall, the priming effect on N400 amplitude was substantial only for targets in the relatedness-judgement task, and displayed a vertex maximum with a central-right bias.

6.3.4.3. P3

P3 was larger parietally (-0.02 μV) than frontally (-2.13 μV) [$F = 12.96$, $p < 0.01$] and larger centrally (-0.47 μV) than the mean of the frontal and parietal sites (-1.08 μV) [$F = 18.98$, $p < 0.001$]. The former difference was larger in the right hemisphere (2.29 μV) than the left hemisphere (1.64 μV) [$F = 6.13$, $p < 0.05$] and the latter difference was larger for the mean of the left and right hemispheres (0.83 μV) than the midline (0.17 μV) [$F = 6.27$, $p < 0.05$]. Overall, P3 displayed a midline-right centro-parietal maximum.

Over the entire scalp, the P3 was considerably larger for the relatedness-judgement task

(1.09 μV) than the silent-reading task (-2.84 μV) [$F = 49.85$, $p < 0.001$]. The P3 was larger in the relatedness-judgement task than the silent-reading task and the difference was larger over the midline region (4.36 μV) than the mean of the left and right hemispheres (3.72 μV) [$F = 19.77$, $p < 0.001$]. The difference between the relatedness-judgement task and the silent-reading task was also larger for the mean of the frontal and parietal sites (4.09 μV) than the central region (3.62 μV) [$F = 6.61$, $p < 0.05$]. Overall, the P3 was considerably larger in the relatedness-judgement task and displayed a central and midline topography. The P3 was non-existent in the silent-reading task.

Across all sites, the P3 was larger for related words (-0.23 μV) than unrelated words (-1.52 μV) [$F = 15.17$, $p < 0.01$]. This difference between related and unrelated words was larger in the right hemisphere (1.40 μV) than the left hemisphere (0.91 μV) [$F = 7.13$, $p < 0.05$] and larger over the midline region (1.57 μV) than the mean of the left and right hemispheres (1.16 μV) [$F = 24.04$, $p < 0.001$]. That is, P3 was larger for related than unrelated words and the difference displayed a midline to right maximum.

Over the entire scalp, related word pairs elicited a large positive P3 (2.35 μV) compared with unrelated word pairs (-0.16 μV) in the relatedness-judgement task, but P3s were negative and equipotential in the silent-reading task (-2.80 μV and -2.88 μV respectively) [$F = 9.56$, $p < 0.01$].

Across all sites, target words (0.86 μV) elicited a larger P3 than prime words (-2.61 μV) [$F = 42.76$, $p < 0.001$]. P3 was larger in the right (1.01 μV) than the left hemisphere (0.54 μV) for target words but equipotential for prime words (-2.49 μV and -2.48 μV

respectively) [$F = 10.52$, $p < 0.01$]. It was similarly larger over the midline (1.03 μV) than the mean of the left and right hemispheres (0.78 μV) for target words, with the reverse for prime words (-2.86 μV and -2.48 μV respectively) [$F = 15.96$, $p < 0.001$]. That is, P3 was large for target responses but not prime responses, and displayed a midline to right hemisphere maximum.

The P3 was much larger for target responses (3.65 μV) than prime responses (-1.47 μV) in the relatedness-judgement task compared with the silent-reading task (-1.93 μV versus -3.75 μV respectively) [$F = 71.41$, $p < 0.001$]. P3 was larger in the right (3.82 μV) than the left hemisphere (3.18 μV) for target responses, with the reverse for prime responses (-1.59 μV and -1.38 μV, respectively) in the relatedness-judgement task. In the silent-reading task the P3 was much smaller overall and displayed a right (-1.79 μV) greater than left hemisphere (-2.09 μV) maximum for target responses, with the reverse for prime words (-4.00 μV and -3.57 μV, respectively) [$F = 8.26$, $p < 0.05$]. The P3 was larger parietally than frontally and the difference was larger for target words (3.07 μV) than prime words (2.08 μV) in the relatedness-judgement task, with the reverse in the silent-reading task (0.61 μV and 2.70 μV respectively) [$F = 24.78$, $p < 0.001$]. This difference was almost equipotential for the mean of the left and right hemispheres (3.08 μV) compared with the midline (3.06 μV) for target words but not for prime words (1.58 μV and 3.04 μV respectively) in the relatedness-judgement task relative to the silent-reading task (target left/right: 0.46 μV and target midline: 0.91 μV, prime left/right: 2.73 μV and prime midline 2.64 μV respectively) [$F = 12.43$, $p < 0.01$]. Overall, the traditional positive P3 was dominant for target responses in the relatedness-judgement task and displayed a parietal midline to right topography.

The P3 was larger for related (2.20 μV) than unrelated (-0.33 μV) target words, but responses to prime words were more equipotential (-2.65 μV versus -2.71 μV respectively) [$F = 44.80$, $p < 0.001$]. The difference between related and unrelated word pairs was larger in the right hemisphere (2.63 μV) than the left hemisphere (1.76 μV) for target responses compared with prime responses (0.14 μV versus 0.09 μV respectively) [$F = 16.78$, $p < 0.001$]. This difference was larger over the midline region (2.75 μV) than the mean of the left and right hemispheres (2.19 μV) for target responses, but the effect was smaller and reversed for prime responses (0.39 μV and 0.12 μV respectively) [$F = 16.07$, $p < 0.001$]. For target responses, the related-unrelated word pair difference was larger parietally (2.62 μV) than frontally (1.92 μV), whereas the effect for prime responses was smaller and reversed (0.20 μV and 0.53 μV respectively) [$F = 13.07$, $p < 0.01$]. The difference between related and unrelated word pairs was also larger centrally (3.37 μV) than the mean of the frontal and parietal sites (2.43 μV) over the midline region compared with the mean of the left and right hemispheres (2.21 μV and 2.19 μV respectively) for target words relative to prime words (central midline: 0.63 μV and frontal/parietal midline: 0.26 μV, central left/right: 0.13 μV and frontal/parietal left/right: 0.11 μV respectively) [$F = 9.29$, $p < 0.01$]. That is, the P3 was larger for related than unrelated target responses and the difference displayed a right parietal to central midline topography, compared with prime responses which were much more equipotential.

The P3 elicited by related targets was larger than that for unrelated targets, and the difference was larger in the relatedness-judgement task (4.48 μV) than the silent-reading task (0.28 μV); this difference was very small and more equipotential across task for

responses to primes (0.54 μV and 0.13 μV, respectively) [$F = 21.91$, $p < 0.001$]. In the relatedness-judgement task, this difference was larger centrally (4.94 μV) than the mean of the frontal and parietal sites (4.24 μV) for target responses but small and much more equipotential for prime responses (0.61 μV versus 0.51 μV), whilst small and far more equipotential for both target and prime responses in the silent-reading task (target central: 0.26 μV and target frontal/parietal: 0.29 μV, prime central: 0.01 μV and prime frontal/parietal 0.19 μV) [$F = 13.47$, $p < 0.01$]. That is, the P3 was larger for related than unrelated target responses in the relatedness-judgement task compared with the silent-reading task, and the difference displayed a central maximum.

6.3.4.4. CNV

The CNV, elicited only by primes, was more negative frontally (-3.47 μV) than parietally (-1.52 μV) [$F = 11.92$, $p < 0.01$] and for the mean of the frontal and parietal sites (-2.50 μV) than the central sites (-2.08 μV) [$F = 8.93$, $p < 0.01$], indicating a strong frontal topography. The CNV was also more negative over the midline (-2.56 μV) than the mean of the left and right hemispheres (-2.25 μV) [$F = 11.61$, $p < 0.01$]. The frontal-parietal difference was larger in the right hemisphere (2.06 μV) than the left hemisphere (1.28 μV) [$F = 5.42$, $p < 0.05$] and largest over the midline region (2.48 μV) compared with the mean of the left and right hemispheres (1.67 μV) [$F = 10.74$, $p < 0.01$]. The central-frontal/parietal difference was larger for the mean of the left and right hemispheres (0.71 μV) than the midline region (0.18 μV) [$F = 26.11$, $p < 0.001$]. Overall, the CNV displayed a frontal midline to right topography.

As noted above, the CNV was more negative over the midline region than the mean of the

left and right hemispheres, and this difference was larger for the silent-reading task (0.43 μV) than the relatedness-judgement task (0.10 μV) [$F = 12.16$, $p < 0.01$]. The frontal-parietal difference was larger for the relatedness-judgement task over the midline region (2.75 μV) than the mean of the left and right hemispheres (1.63 μV), compared with the silent-reading task (2.18 μV versus 1.71 μV respectively) [$F = 7.47$, $p < 0.05$]. The central-frontal/parietal difference was larger for the mean of the left and right hemispheres (0.76 μV) than the midline region (0.22 μV) for the silent-reading task compared with the relatedness-judgement task (0.67 μV versus 0.57 μV respectively) [$F = 8.72$, $p < 0.01$]. Overall, the CNV displayed a frontal midline maximum for the relatedness-judgement task and a midline to frontal right topography in the silent-reading task.

6.3.4.5. Slow Wave

The Slow Wave, elicited only by target words, was more negative in the left (-1.71 μV) than the right hemisphere (-0.06 μV) [$F = 49.84$, $p < 0.001$]. It was more negative for the mean of the frontal and parietal sites (-1.30 μV) than the central site (-0.97 μV) [$F = 13.73$, $p < 0.01$]. Overall, the negative Slow Wave was maximal frontally in the left hemisphere.

Over the entire scalp, the Slow Wave was more negative for unrelated targets (-1.72 μV) than related targets (-0.66 μV) [$F = 8.21$, $p < 0.05$]. The difference was larger in the right hemisphere (1.53 μV) than the left hemisphere (0.34 μV) [$F = 46.01$, $p < 0.001$] and larger over the midline region (1.40 μV) than the mean of the left and right hemispheres (0.88 μV) [$F = 19.96$, $p < 0.001$]. The difference was also larger centrally (2.10 μV) than

the mean of the frontal and parietal sites (1.06 μV) for the midline region compared with the mean of the left and right hemispheres (0.87 μV and 0.84 μV respectively) [$F = 16.85$, $p < 0.001$]. That is, the Slow Wave was larger for unrelated responses than related responses and this effect displayed a vertex to right hemisphere maximum.

The Slow Wave was more negative for the mean of the left and right hemispheres (-1.54 μV) than the midline (-1.33 μV) for the silent-reading task, and this was reversed in the relatedness-judgement task (-0.77 μV and -1.20 μV respectively) [$F = 8.68$, $p < 0.05$]. It was larger frontally (-2.40 μV) than parietally (0.47 μV) for the relatedness-judgement task, but this was reversed and more equipotential for the silent-reading task (-1.54 μV and -1.74 μV respectively) [$F = 7.67$, $p < 0.05$]. Overall the Slow Wave elicited in the silent-reading task was maximal over the left frontal and parietal regions, whereas the Slow Wave elicited in the relatedness-judgement task displayed a frontal to midline topography.

The Slow Wave was larger for unrelated than related words, and this difference was larger in the relatedness-judgement task (2.03 μV) than the silent-reading task (0.08 μV) [$F = 6.28$, $p < 0.05$]. This difference was larger for the central region (2.56 μV) than the mean of the frontal and parietal sites (1.76 μV) for the relatedness-judgement task compared with the silent-reading task (-0.01 μV versus 0.12 μV) [$F = 13.24$, $p < 0.01$]. That is, in the relatedness-judgement task the Slow Wave was larger for unrelated than related responses and this effect of relatedness displayed a vertex maximum, whereas in the silent-reading task the effect was much smaller and almost equipotential.

6.3.5. ERP TOPOGRAPHY SUMMARY

Where applicable, this section will summarize the topography of the ERP components.

6.3.5.1. ACROSS CONDITIONS

The P2 was maximal over the central-left and parietal-right regions. N400 displayed a midline to right frontal topography. P3 displayed a traditional midline-right centro-parietal maximum.

6.3.5.2. WORD TYPE

The CNV was elicited only by primes in anticipation of the target word and displayed a frontal midline to right topography. P2 was larger for primes and displayed a right parietal, central midline to left topography, whilst responses to targets were smaller and displayed a parietal midline to central left topography. N400 prime responses were larger and displayed a slightly-left, largely frontal topography relative to N400 target responses, which were more equipotential with a weak right frontal maximum. Targets elicited a large P3 compared with primes, with a parietal midline to right hemisphere topography. Prime P3s were much more equipotential across the scalp, but were larger overall in the left and right hemispheres relative to the midline. The negative Slow Wave, elicited only by targets, was maximal frontally in the left hemisphere.

6.3.5.3. RELATEDNESS

P2 was larger for related than unrelated words and this difference was maximal over the vertex. The N400 was larger for unrelated than related words and this relatedness effect was maximal over the vertex. The P3 elicited by related words was larger than for unrelated words; this difference displayed a broad midline to right topography.

6.3.5.4. TASK

P2 was larger in the silent-reading task and displayed a central to right-parietal topography, compared with the relatedness-judgement task, in which it displayed a left hemisphere to parietal-midline topography. The N400 elicited in the silent-reading task was larger and displayed a frontal midline maximum, whereas the relatedness-judgement task produced a smaller N400 with a fronto-central midline to right-frontal maximum. P3 displayed its traditional posterior positivity in the relatedness-judgement task, but was not robust in the silent-reading task.

6.3.5.5. WORD TYPE X TASK

Over the frontal midline region, the CNV to primes was larger for the relatedness-judgement task than the silent-reading task. For P2, the effect of word type was larger in the silent-reading task than the relatedness-judgement task. The P2 elicited in the silent-reading task was larger in prime responses and displayed a parietal maximum with a right bias, whereas target responses displayed a parietal-midline topography. The P2 was also larger in prime responses than target responses in the relatedness-judgement task, and displayed a similar topography but was smaller overall in the silent-reading task. The N400 elicited in the relatedness-judgement task was attenuated compared with that in the silent-reading task and this attenuation was larger for target responses than prime responses. The N400 elicited in the silent-reading task was larger in the left than the right hemisphere and this difference was larger in response to the prime than the target; the N400 elicited in the relatedness-judgement task was almost equipotential when comparing the left and right hemispheres. The traditional positive P3 was dominant only in the relatedness-judgement task for target responses, and displayed a parietal midline to right topography. Overall, the Slow Wave to targets was larger in the relatedness-judgement

task and displayed a midline to frontal topography, relative to the silent-reading task, where it was maximal over the left frontal and parietal regions.

6.3.5.6. WORD TYPE X RELATEDNESS

The CNV, elicited only to primes, did not display a relatedness effect. Related targets elicited a larger P2 than unrelated targets, but this relatedness effect was not apparent in responses to primes. The unrelated-related difference displayed a midline maximum for targets but was almost equipotential for primes. Unrelated targets elicited a larger N400 than related targets (the traditional priming effect) and this effect displayed a strong vertex topography; the effect was not elicited by primes. The P3 was larger for related than unrelated target responses and the difference displayed a right parietal to central midline topography; again, this effect did not occur in prime responses. The Slow Wave, elicited only by targets, was larger in response to unrelated words than related words, and this difference displayed a vertex to right hemisphere maximum.

6.3.5.7. TASK X RELATEDNESS

The P2 elicited by related word pairs was larger than that to unrelated word pairs in the relatedness-judgement task, with the effect smaller and reversed in the silent-reading task. The N400 amplitude was larger for unrelated than related word pairs and the difference displayed a strong vertex maximum in the relatedness-judgement task but was almost zero in the silent-reading task. Related word pairs elicited a larger positive P3 than unrelated word pairs in the relatedness-judgement task, but P3s were negative and equipotential in the silent-reading task.

6.3.5.8. WORD TYPE X TASK X RELATEDNESS

The CNV was only found following prime words and did not display a relatedness effect

for either task. P2 was larger for related target responses than unrelated target responses in the relatedness-judgement task and the difference displayed a frontal left maximum. The difference between related and unrelated target responses in the silent-reading task was smaller and more equipotential. The prime responses associated with related and unrelated targets were almost equipotential in both the silent-reading and relatedness-judgement task. The priming effect on N400 amplitude was substantial only for targets in the relatedness-judgement task, and displayed a vertex maximum with a slightly right bias. The P3 was larger for related than unrelated target responses only in the relatedness-judgement task, and this difference displayed a central maximum. The Slow Wave was only elicited by target words, and was larger for unrelated than related responses in the relatedness-judgement task. This relatedness effect displayed a vertex maximum, whereas in the silent-reading task the effect was smaller and almost equipotential.

6.4. DISCUSSION

6.4.1. CNV

The slow negativity developing only after presentation of the prime words, presumably in anticipation of the target, was consistent with the contingent negative variation in terms of its frontal topography and latency (Hillyard, as cited in McCallum & Knott, 1973; Holcomb, 1988; McCallum, as cited in Desmedt, 1979; Rohrbaugh & Gaillard, as cited in Gaillard & Ritter, 1983). The CNV is assumed to reflect cognitive processing associated with the preparation or anticipation of a stimulus event, which is consistent with the current tasks (Donchin, Gerbrandt, Leifer, & Tucker, 1972; Hillyard, as cited in McCallum & Knott, 1973; Holcomb, 1988; McCallum, as cited in Desmedt, 1979; Rohrbaugh & Gaillard, as cited in Gaillard & Ritter, 1983). As expected, it occurred in

both tasks, displaying a midline to right frontal distribution in the silent-reading task and a frontal-midline topography in the relatedness-judgement task; the latter topography was similar to that in the letter-search task of Experiment 1. The difference in CNV topography between the two tasks may reflect differential processing of the primes or, more likely, differential preparatory activities prior to the target. The latter interpretation is most consistent given that the CNV topography was similar to that in the letter-search task of Experiment 1 and the relatedness-judgement task in the current experiment. Both these tasks required preparation or anticipation of a stimulus event in order to process the stimuli to perform the task. In the silent-reading task the preparatory processing was reduced because information associated with the prime was not required to be held in order to process the target.

6.4.2. P2

The positive component peaking at approximately 250 ms post prime and target onset was consistent with the P2 component (Luck & Hillyard, 1994; McDonough, Warren, & Don, 1992; Raney, 1993). This component has been associated with short-term memory storage, particularly in tasks requiring the matching of successive stimuli (Chapman, McCrary, & Chapman, 1981; Friedman, Vaughan, & Erlenmeyer-Kimling, 1981).

The P2 was larger for related than unrelated targets in the relatedness-judgement task and displayed a frontal left topography. However, this priming effect was absent in the silent-reading task. This is consistent with the earlier findings mentioned because the relatedness-judgement task would have required matching of successive stimuli in order to make a decision. The P2 has been associated with the retrieval of aspects of semantic information from long-term memory which are then used in working memory (Raney,

1993; Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988). Whilst it is important to acknowledge that ERPs are scalp recorded, the underlying structures in the frontal left region are often implicated with semantic processing and activation, and the topography of the P2 priming effect may be a reflection of this (Buckner, Raichle, & Petersen, 1995; Petersen et al., 1989).

6.4.3. N400

The statistical analysis used in the current experiment again showed that the processing associated with prime words was similar to that for target words, particularly in relation to the traditional N400 latency range. As in the previous experiment, the PCA of the voltage x time function spanning the prime and target extracted single factors with pairs of component peaks occurring for both prime and target over a similar time frame after stimulus onset (e.g., Factors 2, 3 and 6). As noted earlier, this implies that the underlying cognitive processes associated with prime processing are not distinct from those used to process the target. Based on the findings of Näätänen and Picton (as cited in McCallum, Zappoli, & Denoth, 1986) it is assumed that the N400 is one of a group of distinct N2 components that can contribute to the overall N2 deflection. This supports the assignment of a single nomenclature of N400 to processing over this latency range for both prime and target, as introduced in the first experiment.

Semantically-related targets were associated with shorter reaction times and an attenuation of N400 amplitude compared with unrelated targets. This ERP priming effect was evident over the interval 300 ms - 450 ms post target onset and, as anticipated, it was larger for the relatedness-judgement task than the silent-reading task. The latency and sensitivity of the ERP component to semantic priming was consistent with the N400 component reported in

research using word pairs and lists. The central right-midline topography of the priming effect in the relatedness-judgement task was consistent with the commonly-reported central to parietal scalp distribution, often with an asymmetry favouring the right hemisphere (Bentin, 1987; Bentin et al. 1985; Brown & Hagoort, 1993; Holcomb, 1988, 1983; Kutas & Hillyard, 1980a, 1980b, 1982, 1989; McCarthy & Nobre, 1993; Young & Rugg, 1992).

6.4.4. P3

A semantic priming effect on P3 amplitude was obtained for targets. The P3 priming effect was evident over the interval 450-800 ms. The P3 was maximal over the parietal region of the midline to right hemisphere for target words rather than prime words in the relatedness-judgement task, but was almost absent and more equipotential in the silent-reading task. This confirms that the P3 component is sensitive to some aspects of the relatedness judgement task.

It has been well documented that the P3 is elicited by tasks that require stimulus evaluation and is largest when the response to task-relevant stimuli is overt and immediate (Bentin, 1987; Bentin et al., 1985; Donchin & Coles, 1988; Herning, Speer, & Jones, 1987; Neville et al., 1986; Rugg, 1987). The current results are consistent with this interpretation. That is, it can be considered that a large P3 was elicited in the relatedness-judgement task because of the stimulus evaluation required to make the overt binary decision regarding the relatedness of the target to the prime. The silent-reading task did not require stimulus evaluation and such tasks have often resulted in an attenuation or elimination of the P3 component (Kutas & Hillyard, 1980, 1982, 1983, 1984; Rugg, 1987), as was the case in the current study.

6.4.5. SLOW WAVE

In the relatedness-judgement task the Slow Wave displayed a frontal topography 800 - 1300 ms post target onset. This was consistent with the literature in terms of scalp distribution and latency (Holcomb, 1988; McCallum, as cited in Desmedt, 1979; Rösler, Heil, & Glowalla, 1993; Uhl et al., 1990). Over tasks, unrelated targets elicited a larger Slow Wave than related targets and this effect displayed a right to central midline topography. The effect was dominant in the relatedness-judgement task, where it displayed a vertex maximum. The enhanced negativity to unrelated targets in this task may reflect an exhaustive search of the associative structure in long-term memory, whereas the search for related targets would have been self-terminating. That is, in the relatedness-judgement task subjects may have adopted a strategy of exhaustively searching long-term memory to determine whether the target was related to the prime, even though the effect displayed a central distribution rather than the more traditional frontal activation usually associated with such a search. There was no relatedness effect for the Slow Wave to targets in the silent-reading task, suggesting that there was no active retrieval of semantic attributes from long-term memory.

6.4.6. COMPONENT OVERLAP

A function of the PCA was to allow the selection of latency ranges which minimized component overlap, but this does not imply that one component cannot influence another, in relation to latency and amplitude, over the selected latency range. An important issue is whether the priming effect on N400 amplitude elicited by target words in the relatedness-judgement task could be attributed to component overlap with the P2 and/or P3 and/or the Slow Wave. It is commonly recognised that differences in N400 amplitude may be confounded by changes in P3 amplitude and/or shortened latency (Boddy, 1986;

Chwilla, Hagoort, & Brown, 1998). This argument should also incorporate the overlap between P2, N400, P3 and the Slow Wave. It has been reported that P3 latency covaries with reaction time measures and reflects the time required to evaluate the stimulus (Chwilla, Hagoort, & Brown, 1998; Donchin & Coles, 1988; Donchin, Ritter, & McCallum, as cited in Callaway, Tueting, & Koslow, 1978; Duncan-Johnson, 1981; Kutas, McCarthy, & Donchin, 1977; Magliero, Bashmore, Coles, & Donchin, 1984). The relatedness-judgement task in the present study elicited a P3 broadly corresponding in latency with reaction time. That is, there was a delay in P3 latency for the unrelated target words, which corresponded with an increase in their reaction time. The delay in P3 latency to unrelated target words could reflect more effort in resolving the semantics associated with the unrelated word. This implies that the attenuation in N400 amplitude to unrelated words could be the result of condition differences in the P3.

The P2, N400, P3 and Slow Wave components all displayed a relatedness effect. For the components with a negative polarity, N400 and Slow Wave, related targets were smaller in amplitude than unrelated targets. For components with a positive polarity, related targets were larger in amplitude than unrelated targets. That is, the relatedness effect was in the same direction for components of the same polarity.

However, if an effect of relatedness in a component is due solely to that effect in another component, the effect should have the same topography. The issue of component overlap will be addressed by assessing the topographic differences and similarities between the CNV, P2, N400, P3 and Slow Wave components in the analyses involving the variable of relatedness.

Overall, the P2 relatedness effect was maximal over the vertex, as was the N400 effect, whereas the P3 effect displayed a midline to right hemisphere distribution. The similarity in the distribution of the overall relatedness effects in P2 and N400 suggests that the components could have influenced each other. That is, the priming effect on N400 amplitude may reflect attenuation of responses to related targets due to overlap with an enlarged P2 in the same condition. This is less likely for P3 since its overall relatedness effect showed a topography distinct from that of the effect in the N400.

In relation to the interaction between 'word type' and 'relatedness', a priming effect occurred for the P2, N400, P3 and Slow Wave components, but only for target responses. This displayed a midline maximum for P2, a strong vertex maximum for N400, a right parietal to vertex topography for P3 and a vertex to right hemisphere topography for the Slow Wave. The similarity in the topography between the N400 and P2 word type X relatedness effects again suggests the possibility of overlap between effects in these components. Some difference in topography did emerge between the N400 and P3 for the word type X relatedness effects which may indicate that the priming effects are relatively independent. However, the overlap in the topography of this priming effect (word type X relatedness) for the P3 and Slow Wave components suggests the likelihood of the effect in one component overlapping and affecting the other.

The interaction between 'word type', 'task' and 'relatedness' is the most important in dealing with the issue of component overlap. The priming effects for P2, N400 and P3 were substantial only for targets in the relatedness-judgement task. The Slow Wave was only elicited in response to targets and it too displayed a substantial priming effect only in the relatedness-judgement task. Topographically, this effect displayed a left frontal

maximum for P2, was maximal over the vertex with a slightly right-central bias for N400, displayed a central maximum for P3 and a vertex maximum for the Slow Wave. The thrust of the argument is that if an effect of relatedness is due solely to another component it should have the same topography. The topographic difference between the P2 and N400 makes it unlikely that the priming effect on N400 amplitude reflects attenuation of responses to related targets due to overlap with an enlarged P2. However, topographies associated with the priming effect in the Slow Wave, P3 and N400 component amplitudes do overlap sufficiently to be unable to rule out the effect of component overlap.

In summary, the effect of relatedness, the interaction of word type x relatedness and word type x task x relatedness all displayed some degree of topographic overlap between components. The only exception was the P2 component in the word type x task x relatedness interaction which was distinctly maximal over the frontal left region. Overall, the overlap in topography indicated that a *broad* relatedness effect may exist which impacts on the N400, P3 and Slow Wave components for target responses in the relatedness-judgment task.

Smith (1993) suggested that relationships may exist among components that vary in respect to task. The priming effect was task specific and may reflect the flexibility of the language system in processing the relatedness information at varying stages to enable efficient task performance.

6.5. CONCLUSION

As in the previous experiment, the PCA of the voltage x time function spanning the prime and target extracted single factors with pairs of component peaks occurring for both prime

and target over a similar time frame after stimulus onset (Factors 2, 3 and 6). This finding indicates a consistency between experiments, showing that the underlying cognitive processes associated with prime processing are not distinct from those used to process the target. This underlying cognitive processing is reflected in the P2, N400 and P3 components. This experiment supports the previous finding that the N400 is one of a group of N2 components that can contribute to the overall N2 deflection and involves similar processing for prime and target, supporting the use of a single nomenclature of N400.

The larger priming effects on N400 amplitude in the relatedness-judgement task relative to the silent-reading task support the conclusions of Experiment 1 and previous findings showing that the magnitude of the priming effect on N400 amplitude is influenced by the extent to which the task encourages subjects to attend and utilize semantic information (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995, Deacon, Breton, Ritter, & Vaughan, 1991; Kellenbach & Michie, 1996; Rugg, Furda, & Lorist, 1988). That is, the extent of the priming effect on N400 amplitude is not determined by "whether the semantic relationship between words is relevant to the task, but whether the words are processed semantically" (Deacon, Breton, Ritter, & Vaughan, 1991, p. 198; Stolz & Besner, 1996).

The following section will interpret the semantic priming effects on N400 amplitude in relation to models of semantic memory. The three-process model proposed by Neely and Keefe (as cited in Bower, 1989) identifies three priming mechanisms, spreading activation, expectancy-induced priming and semantic matching/integration. Experiment 1 alluded to the fact that the mere presence of an N400 in the absence of any priming effect

on N400 amplitude may indicate that the N400 is an automatic process, possibly associated with lexical access and the spread of activation to related units. The current experiment supports this interpretation because the N400 component was identified for primes. However, the N400 elicited by primes was larger in the silent-reading task relative to the relatedness-judgement task. Whilst the N400 component may reflect automatic processes it was also influenced by task, implying that N400 amplitude can vary depending on how attention is directed by the task. Also the priming effect on N400 amplitude for targets in the relatedness-judgement task was larger than that associated with the silent-reading task, indicating that the N400 effect is not merely an automatic process because such a process should not differ in respect to task. The results of this experiment support previous findings showing that the priming effect on N400 amplitude does not merely reflect the automatic process of spreading activation. The implication of the N400 differences in relation to task is that it most likely represents controlled post-lexical processes, possibly associated with expectancy-induced priming and/or semantic matching/integration. The current experiment is unable to distinguish these post-lexical mechanisms. Alternatively, these controlled post-lexical processes may involve some aspect of lexical access, assumed to be an automatic process associated with spreading activation. This is consistent with literature that has suggested that the N400 represents automatic and controlled aspects of processing (Ziegler, Besson, Jacobs, Nazir, & Carr, 1997; Hinojosa, Martín-Loeches, & Rubia, 2001)

Note however that the differences between tasks in the target N400 priming-effect show that task demands influence the activation of the integration process. This is contrary to the growing view that the priming effect on N400 amplitude reflects a mandatory post-lexical integration process (Chwilla, Hagoort, & Brown, 1998; Hagoort, Brown and

Swabb, 1996).

The priming results can also be interpreted in the compound-cue model proposed by Ratcliff and McKoon (1988). An integrative mechanism is proposed to join the prime and target during encoding, and this is associated with a familiarity value. Priming occurs because related word pairs are associated with a higher familiarity value than unrelated word pairs. Related responses in the relatedness-judgement task show an attenuation of N400 amplitude that may reflect the higher familiarity value between prime and target.

Connectionist models can also account for the semantic-priming effects. Such models use distributed memory representations, and associated words are assumed to have similar patterns of activation (Masson, as cited in Besner & Humphreys, 1991, 1995). The prime causes activation of semantic patterns associated with related words. Priming emerges because the activation pattern associated with a related target word stabilises faster than that for an unrelated target word. The priming effect on N400 amplitude in response to target words could reflect this stabilisation process.

An N400 was also elicited by the prime and it is important to determine whether the underlying processing differs from the target. The frontal distribution of the N400 elicited by primes and the central topography of the N400 elicited by targets implies that, although the components are the same, they reflect a variation in processing. It was concluded in Experiment 1 that the N400 itself may reflect the automatic process of spreading activation. This is ruled out by the current experiment because primes elicited a larger N400 in the silent-reading task than in the relatedness-judgement task. By definition, an automatic process should not show task differences, which rules out spreading activation.

This interpretation hinges on how automaticity is conceptualised.

Stolz and Besner (1996) suggest that the concept of 'automaticity' has been used as a theoretical means of describing a process or outcome, and they prefer to conceptualise mind as an interactive system, balancing between bottom-up and top-down influences. The notion of automaticity seems redundant in the interactive activation framework because it is assumed that participants generate a set regardless of the task. This set serves to consciously bias focal attention to interpret patterns of activation at particular levels of the Interactive Activation model of word recognition.

The current experiment showed that semantic-priming effects on P2, N400, P3 and Slow Wave amplitudes can be influenced by task. Task instructions modulated the extent of integration with the attended context provided by the prime. The effect of task on N400 amplitude in relation to prime and target processing can be interpreted as differences in the flow of activation between the two tasks. This difference in the flow of activation can be "conceptualised as a reflection of the 'set' adopted by the participant" (Stoltz & Besner, 1996, p. 1175). As mentioned earlier, the notion of 'set' has been described as the top-down influence on perception/behaviour (Neisser, 1967; Stolz & Besner, 1996). Henderson (as cited in Coltheart, 1987) described the top-down influence as the ability of an individual to control performance by biasing attention to different levels of representation in the network model, thus altering the distribution of activation across the network by biasing the gain between levels. Kellenbach and Michie (1996) reported that a priming effect on N400 amplitude elicited by target words occurred only when the prime was processed in the focus of attention, which was assumed to deliver the word's meaning for the integrational process with the target word. It was concluded that the N400

amplitude elicited by target words is modulated by the ease of integration with the attended context provided by the prime.

It can be extrapolated that the attenuation in N400 amplitude elicited in the present study by prime words in the relatedness-judgement task relative to the silent-reading task may reflect differences in the flow of activation throughout the system due to the set adopted by the subjects. In the relatedness-judgement task this may represent the conscious biasing of focal attention, altering the distribution of activation across the network to favour a semantic level of representation in order to deliver the prime's meaning in anticipation of the integration process with the target word.

The almost-absent priming effect on N400 amplitude to target words in the silent-reading task can be interpreted in two different ways. A consequence of the 'set' adopted by participants in the silent-reading task might be that the system was biased to interpret patterns of activation from the letter level to the word level, preventing the flow of activation to the semantic level, even though this is usually assumed. Alternatively, the set adopted biased the system to interpret patterns of information from the letter level to the word and semantic levels - but only in a bottom-up fashion, 'blocking' top-down processing. Silent-reading of the prime and target words may have been completed using bottom-up processing without the need for the integration, which is assumed to be associated with top-down processing.

Even though semantic associates of the prime may have been activated at the semantic level, the silent-reading task could be performed without the need to integrate the target and prime. Since the priming effect on N400 amplitude has been suggested to reflect the

ease of this integration process (Kellenbach & Michie, 1996), the lack of such an effect in the silent-reading task supports the contention that such processing may not have occurred.

Overall, the N400 elicited by prime words may reflect lexical access and the consequent spreading activation at the semantic level, emerging as a result of bottom-up processing. On the other hand, the priming effect on N400 amplitude may reflect an integrative process resulting from top-down processing.

The components identified using PCA were the CNV, P2, N400, P3, and the Slow Wave. Of these, the P2, N400 and P3 components reflect underlying cognitive processes associated with the processing of the prime that are not distinct from those used to process the target in word-pair tasks, specifically confirming the identification of the N400 as one of a group of N2 components. The multi-tasking approach showed that semantic priming effects are influenced by the task performed. Task instructions modulated the extent of integration with the attended context provided by the prime, and this was proposed to be due to the influence of 'set' on processing. The influence of task on the magnitude of the priming effect on N400 amplitude demonstrates that it is due to post-lexical integration processes.

The influence of component overlap on semantic priming in the relatedness-judgement task was also addressed. The priming effect on the P2 amplitude displayed a topography (left frontal) distinct from the N400 (vertex with a right-central bias), P3 (central) and Slow Wave (vertex) components for target responses in the relatedness-judgment task. The priming effect for the N400, P3 and Slow wave amplitude displayed a distinct but

overlapping topography, indicating that a *broad* relatedness effect may exist which impacts on the N400, P3 and Slow Wave components for target responses in the relatedness-judgment task. The silent-reading task was used to shed light on the issue of component overlap between the priming effect on N400 and P3 amplitude because the task did not require an overt response, commonly associated with the P3. An N400 was elicited by targets in the absence of the P3 component but there was little priming effect in N400 amplitude, making it difficult to establish the independence of the priming effect on N400 and P3 amplitude. This issue of component overlap could be addressed by using a task that invokes a greater priming effect on N400 amplitude without any overt response requirements.

In summary, the PCA in the current experiment showed that the components elicited by primes and targets were similar in both tasks, supporting the findings in Analysis 3 of Experiment 1. As in Experiment 1, the mere presence of the N400 for both primes and targets in the silent-reading task implies that the N400 reflects automatic processing. However, the difference in the magnitude of the N400 amplitude in responses to primes (silent-reading > relatedness-judgement) and the difference in the N400 priming effect for targets (relatedness-judgement > silent-reading) suggest that this ordinarily automatic process can be controlled, depending on task demands.

The word X task X relatedness interaction clearly indicated that priming effect on P2 amplitude was distinct from the other components topographically. The priming effect on N400, P3 and Slow Wave amplitude displayed a maximal topography which was distinct but overlapping. It was concluded that a *broad* relatedness effect may exist which impacts on the N400, P3 and Slow Wave components for target responses in the

relatedness-judgment task. The use of experimental design techniques to dissociate the priming effect on N400 and P3 amplitude was not completely successful. Although the silent-reading task did not elicit a P3 component, the priming effect on N400 amplitude was not distinct enough to conclude that the N400 effect occurs in the absence of a P3 effect.

The dissociation of the N400 and P3 may still be achieved by implementing a task which elicits an N400 effect when there is no overt response. As mentioned previously, P3 is absent or reduced following the N400 when there is no overt response (Fischler, Childers, Achariyapaopan, & Perry, 1985). If the positivity following the N400 was absent then any priming effect on N400 amplitude could not be attributed to amplitude variation in the P3.

CHAPTER 7

EXPERIMENT 3

7.1. INTRODUCTION

Experiment 2 addressed the influence of component overlap on priming, particularly in relation to the N400 and P3 components. This issue was investigated by comparing the silent-reading and relatedness-judgement tasks. In the relatedness-judgement task it was clearly shown that the influence of component overlap on the N400 priming effect was not restricted to the P3 component, but also involved the Slow Wave component. However, the silent-reading task did not necessitate analysis of semantic features and failed to elicit a robust priming effect on N400 amplitude. Hence that task was replaced in this experiment with a memorisation task, which was assumed to increase the extent of semantic analysis. For example, Bentin et al. (1993) used the N400 component to examine semantic-priming effects while manipulating the extent of semantic elaboration required to process primes and targets in the auditory modality. Their subjects were required to perform two tasks, in one of which they had to study a list of words and perform a subsequent recognition test. In the other, subjects performed a lexical-decision task in which they were required to keep a silent count of nonwords. The N400 priming effect was found to occur only in the memorisation task. They suggested that "the amount of attention directed to semantic analysis appears to be important in determining the size of the N400 priming effect" (p. 167).

The memorisation task required subjects to memorize the word pairs and perform a

subsequent recognition-memory test. This task does not require an immediate overt response, and hence was not expected to be associated with a substantial P3. Therefore, any priming effect on N400 amplitude elicited in the memorisation task should not be confounded by component overlap due to P3. The memorisation task was compared with the relatedness-judgement task used in the previous experiment, in which subjects determined whether the targets were related to the primes and indicated this by making an overt response.

It was assumed that both tasks involve semantic processing because of the way attention is initially directed by the tasks. That is, in the memorisation task it was assumed that subjects *implicitly* use the semantic relationship between the word pairs to facilitate later recognition. Because subjects are made aware of the semantic relationship between word pairs in the relatedness-judgement task, they *explicitly* attend to this semantic relationship in order to make a relatedness judgement.

The results will be interpreted in the framework of the Stolz and Besner (1996) model of word recognition, as in the previous experiments. It is assumed that the task demands associated with the relatedness-judgement and the memorisation tasks require semantic processing and bias the system to interpret patterns of activation at the semantic level. Again it is assumed that task demands are likely to require subjects to adopt top-down processes to modulate the flow of activation.

Using the N400 as an index of semantic processing of target words, a priming effect on N400 amplitude for target words was anticipated in both tasks. A priming effect on reaction time (RT) was expected in the relatedness-judgement task. A priming effect was

also anticipated in the recognition test, that is, related word pairs would be more easily recalled than unrelated word pairs or word pairs not previously seen.

In addition, the experiment attempted to support the findings of the previous experiments indicating that the locus of the priming effect reflects a controlled rather than an automatic priming mechanism. Any differences in the priming effect on N400 amplitude due to task would support this interpretation because a truly automatic process such as spreading activation would not be affected by changing the level of processing. As mentioned previously, a lack of task differences in the N400 effect would make it difficult to determine the locus of the effect in relation to lexical-access and post-lexical processes because the effect could emerge due to either process.

The most important methodological contribution of this thesis thus far has been the use of PCA across the voltage x time function spanning both prime and target. This approach will again be adopted to confirm earlier findings indicating that the underlying processes used in processing the prime are similar to those used to process the target. The previous experiments identified the following components as those elicited by both prime and target: P2, N400, and P3. The CNV was identified only in relation to prime processing, and the Slow Wave was associated only with target processing. Similar components are expected to be identified in the current experiment.

7.2. METHOD

7.2.1. SUBJECTS

Nineteen university students (17 females and 2 males) aged between 19 and 33 years (mean = 20.2 yrs) participated in the experiment as one means of satisfying a course

requirement. All subjects spoke English as their first language and had normal or corrected-to-normal vision.

7.2.2. STIMULI AND DESIGN

One hundred and twenty semantically-associated word pairs (primes/targets) and one hundred and twenty semantically-unrelated word pairs from the previous experiment were used, each word being 3-8 letters (mean = 5.2 letters). Primes were also matched on word length.

The experiment consisted of a memorisation task with a subsequent recognition test, and a relatedness-judgement task. Sixty semantically-associated word pairs and sixty unrelated word pairs were assigned to each condition. The stimuli were randomised, except that no more than three related or unrelated word pairs occurred consecutively and no prime was related to the preceding target.

Each task consisted of 120 primes and targets presented consecutively. Stimuli were presented foveally on a monitor, with each word exposed for 200 ms, with an inter-stimulus interval of 400 ms. The inter-trial interval was 2000 ms, during which a fixation point was presented. The viewing distance was 110 cm and the stimuli were presented in upper case letters 10 mm high and 5 mm wide. Reaction times collected in the relatedness-judgement task were considered valid only if they occurred during the inter-trial interval and corresponded to the predetermined definition of a related or unrelated target.

Subsequent to the presentation of stimuli in the memorisation task, a pencil and paper recognition task was performed. It consisted of 160 primes and targets, 80 of which were semantically-associated word pairs and 80 unrelated word pairs. Of the 80 stimulus pairs in each category, 40 had been previously presented in the memorisation task (old) and 40 were previously unseen (new). The new stimuli were the unused 80 stimulus pairs from the previous experiment and were matched on word length to those used in the memorisation phase. The stimuli were randomised as mentioned above with the addition that no more than three related or unrelated word pairs that had been seen previously occurred consecutively.

7.2.3. ERP RECORDING

An electrode cap was used to record EEG activity from 9 scalp electrodes. The 10-20 system was used to determine electrode position (Jasper, 1958) at frontal (Fz), central (Cz) and parietal (Pz) midline sites, and frontal (F3, F4), central (C3, C4) and parietal (P3, P4) lateral sites, with linked earlobes used as the reference. Electrodes above and below the right eye were used to monitor vertical eye movement (VEOG), and a right to left canthal bipolar montage was used to monitor horizontal eye movement (HEOG). The impedance at each electrode was less than 5 kOhm, and activity was amplified (EEG gain = 20,000; EOG gain = 5,000) with a bandpass of 0.01-35 Hz. EEG was continuously recorded at 256 Hz per channel and stored for offline analysis. From this, 2000 ms epochs of EEG were taken from 100 ms before each prime.

7.2.4. PROCEDURE

Experimental trials were presented in two blocks of 120 word pairs. In one block, subjects were instructed to memorise the word pairs as they appeared on the screen with

the instruction that they would be required to recognise them later. Subjects were kept naïve about the semantic relationship between the word pairs. In the other block, subjects performed a relatedness-judgement task by pressing one of two laterally-positioned buttons as quickly and accurately as possible if they considered the target to be related to the prime, and the other if it was considered unrelated. The button assigned to each word type was counterbalanced across subjects. The order of presentation of the memorisation task and the relatedness-judgement task was counterbalanced across subjects. Subjects were also instructed to minimize body and eye movements.

7.2.5. DATA ANALYSIS

Average ERPs for each site were computed, excluding those trials invalidated by excessive eye movement (>±100 μV). Principal components analysis (PCA) was performed for the prime and target words combined, by selecting every eighth point in the data set (Coles, Gratton, Kramer, & Miller, as cited in Coles, Donchin, & Porges, 1986). PCA was carried out from 100 ms pre-prime onset to 1900 ms post-prime onset. All Factors whose eigenvalues exceeded unity were retained. The data collected from two of the nineteen subjects was discarded due to excessive eye movement. The analysis consisted of 2 tasks x 2 word types x 2 relatedness levels x 9 electrodes x 17 subjects, forming 1224 cases. PCA was performed on the covariance matrix using SPSS-X V8 with varimax rotation of factors.

Prior to the statistical analysis of components, mean amplitude measures were established at each site for each of the component latency ranges identified using PCA. The normalization of ERP data across scalp sites was performed using the method described

by McCarthy and Wood (1985). Repeated measures ANOVAs and planned contrasts were used to analyze all data for each component. The reporting of topographic interactions was restricted to those that were significant for the raw data and remained so once normalised. Two subjects were excluded due to excessive eye movement, so that all F tests had (1,16) degrees of freedom; the significance criterion used was $p < 0.05$. There were 3 levels of a lateral factor (left, right and midline), 3 levels of a sagittal factor (frontal, central and parietal), 2 levels of word type (prime and target), 2 levels of task (memorisation and relatedness-judgement), and 2 levels of relatedness (related and unrelated). Within the lateral factor, planned comparisons compared left with right activity, and their mean with activity at the midline. Planned comparisons compared frontal with posterior activity, and their mean with central activity within the sagittal factor. The optimal resolution of topographic effects was achieved by using such planned comparisons, and their single degree of freedom F tests avoid the problems which may occur with non-sphericity of the variance-covariance matrix in repeated-measures designs. The behavioural data were analyzed using a t-test on the 2 levels of relatedness for the relatedness-judgement task; 2 levels of relatedness and the two levels of old/new in the memorisation task. ERP trials were retained in the memorisation task regardless of whether the word pair was remembered correctly.

7.3. RESULTS

All figures below use the abbreviations *mem* and *rj* to indicate the memorisation task and the relatedness-judgment task respectively.

7.3.1. BEHAVIOURAL DATA

In the relatedness-judgement task the mean reaction times of related targets were compared to those of unrelated targets in order to determine behavioural priming effects. Responses were correct in 87% of all trials presented. Reaction times to related targets were significantly faster (557 ms, SD 104 ms) than to unrelated targets (749 ms, SD 155 ms) [$t(16) = -6.695$, $p < 0.001$], indicating that a facilitatory priming effect occurred in the related word pair condition.

In the memorisation task the mean percentage of correctly-recognised old related word pairs was compared to that of old unrelated word pairs in order to determine behavioural priming effects. The mean of correctly-recognised old related word pairs was at a better than chance level (61.0 %, SD 7.4) and significantly greater than correctly-recognised old unrelated word pairs (34.4 %, SD 6.0) [$t(16) = 6.53$, $p < 0.001$], indicating that a facilitatory priming effect occurred in the related word pair memorisation condition. Subjects' recognition of old word pairs was at approximately chance level overall (47.7%, SD 5.9) relative to the erroneous recognition of new word pairs (3.3%, SD 2.5) [$t(16) = 12.60$, $p < 0.001$].

7.3.2. ERPs

For simplicity, two words defining a word pair shall be referred to as 'prime' and 'target' respectively for both the relatedness-judgement and memorisation tasks, even though the description 'target' does not have the same connotation in the memorisation task.

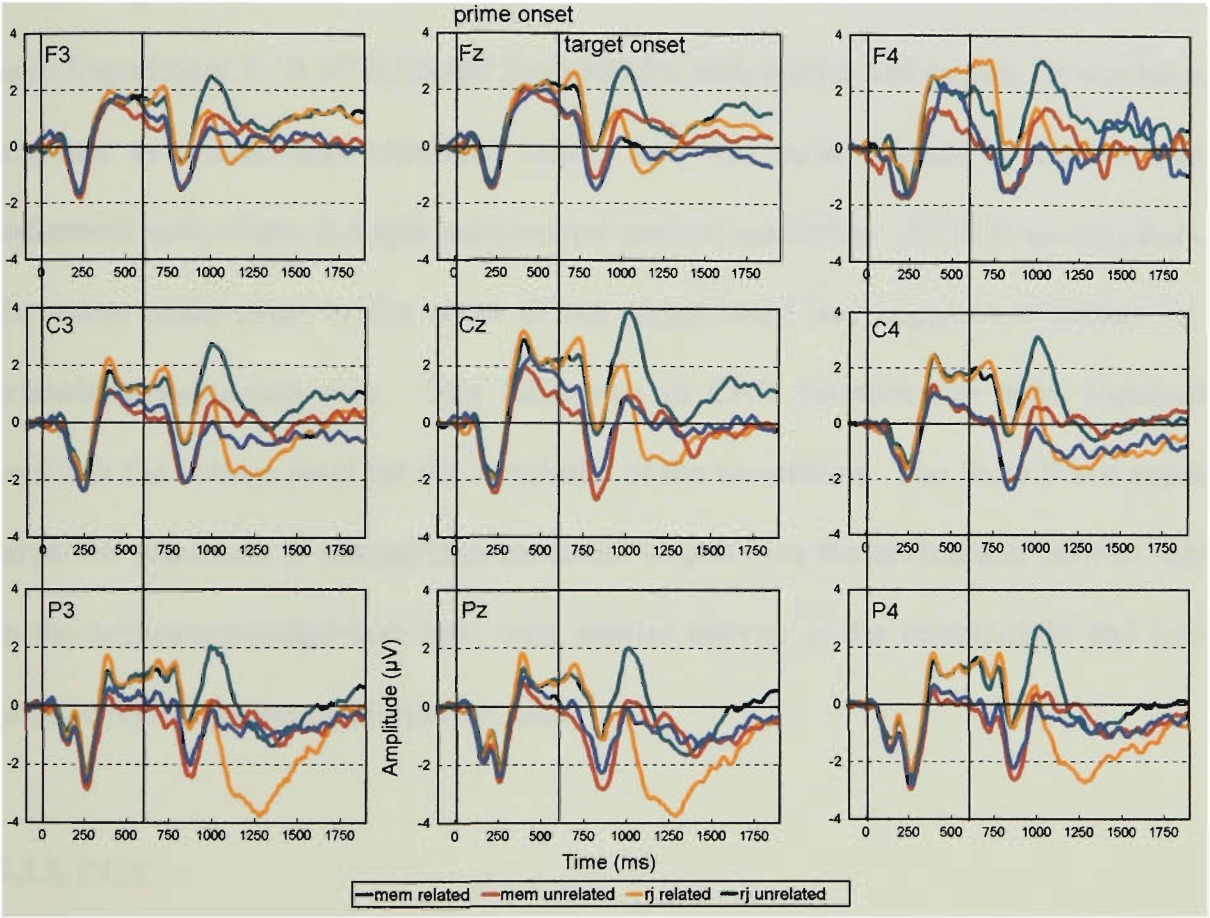


Figure 7.1. Grand average ERPs evoked by related and unrelated prime-targets in the memorisation and relatedness-judgement tasks.

Figure 7.1 illustrates that responses to primes and targets displayed a P1-N1 complex parietally in both tasks. There appears to be a delay in the latency of the parietal P2 compared with the other scalp sites. As reported in the previous experiments, the delay in latency appears to emerge because it occurs after the P1-N1 complex, which displayed a parietal topography. In both tasks, a P2 was evident in the responses to both primes and targets over the entire scalp, with a slight delay parietally (as mentioned above). An N400

was also elicited by primes and targets and appeared over the entire scalp. Primes appeared to elicit a larger N400 over the central and parietal regions in the relatedness-judgement task compared with that associated with the memorisation task. In the relatedness-judgement task, the N400 was larger for responses to unrelated targets than related targets and this effect appeared to be maximal over the central and parietal regions, as in Experiment 2. A P3 followed the N400 for both primes and targets. It was larger in response to related than unrelated targets and was most distinct in the relatedness-judgement task, where it displayed a central parietal maximum. A CNV was evident over the entire scalp prior to the onset of the target word and appeared dominant in the relatedness-judgement task. The difference in CNV between the tasks appeared to establish the voltage level for the remainder of the waveforms. The Slow Wave appeared larger for responses to related than unrelated targets over the central and parietal regions in the relatedness-judgement task, with similar activity in the central-right and frontal-midline regions in the memorisation task.

7.3.3. PCA

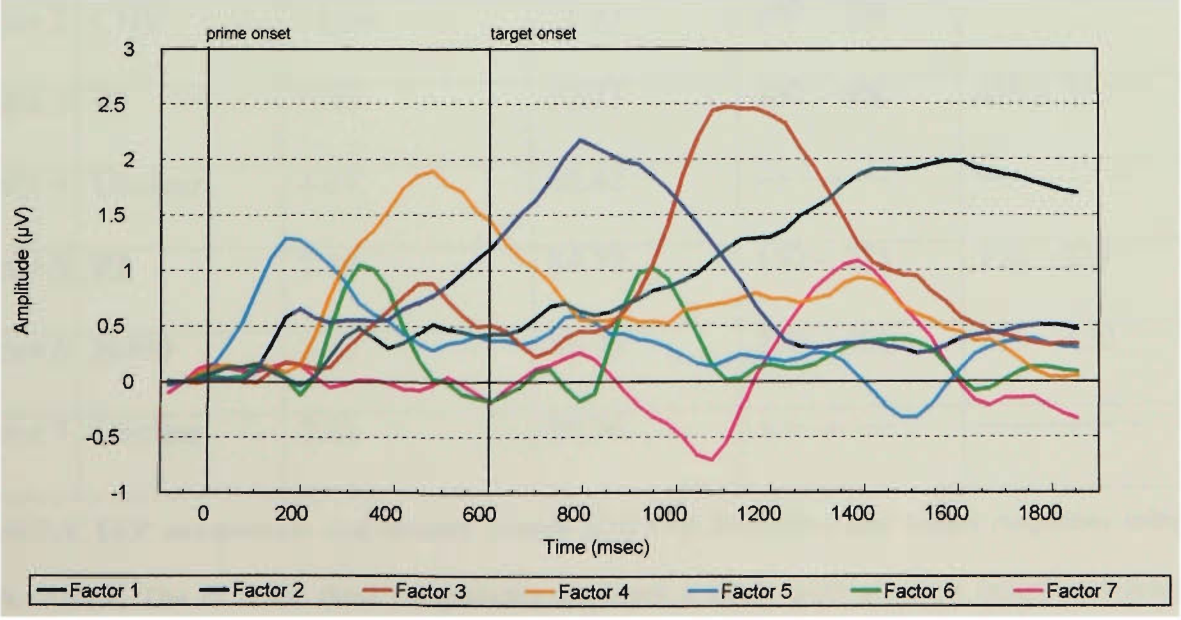


Figure 7.2. Factors extracted using PCA on prime and target responses across a single epoch.

The PCA was consistent with the PCA of the previous experiments (see Figure 7.2). That is, a slowly-varying component accounted for the greatest percentage of variance, followed by the faster-varying components which extended over short temporal ranges. Factor 1 was the slowest varying component, building up across the epoch and peaking 900 ms after target onset. Factor 2 was also a slowly-varying component which peaked approximately 150 ms after target onset. Factor 3 displayed a peak to the prime at 450 ms after prime onset and a larger peak to the target at 500 ms after target onset. Factor 4 was a broad component with a latency range of 200 ms to 700 ms after prime onset. Factor 5 peaked at 200 ms after prime onset with a smaller peak occurring at approximately the same time after target onset. Factor 6 displayed a clear peak for both prime and target of similar magnitudes, peaking 350 ms after prime and target onset. The final component only emerged to the target and displayed peaks at 450 ms and 800 ms after target onset.

Factor	Component	% of Variance explained	Cumulative %	Latency ranges (ms) Prime	Latency ranges (ms) Target
Factor 1	Slow Wave	60.27	60.27		750 – 1300*
Factor 2	CNV	11.66	71.93	600 – 700*	
Factor 3	P3	5.80	77.73	400 – 600	420 – 750
Factor 4	Unclear	4.69	82.42	------------	--------------
Factor 5	P2	2.30	84.72	150 – 275	150 - 275
Factor 6	N400	2.23	86.95	275 – 400	275 – 420
Factor 7	Unclear	2.01	88.96	------------	--------------

Table 7.1. ERP components and latency ranges identified for prime and target responses using PCA. *Note: The PCA for these components displayed a single peak over the indicated latency range. Factor 4 and Factor 7 were not analysed further due to difficulty in identifying their component structure and establishing an appropriate latency range.

However, the factors in the current experiment were extracted in a different order compared to those of the previous experiment, indicating a difference in the variance explained by each factor. The figures below depict the grand average ERPs multiplied by the rotated, rescaled component matrix for each factor, which assisted in the identification of the components derived by the PCA. The latency range associated with the component is shaded in the figures below. A summary of the variance and latency ranges determined using the PCA is shown in Table 7.1.

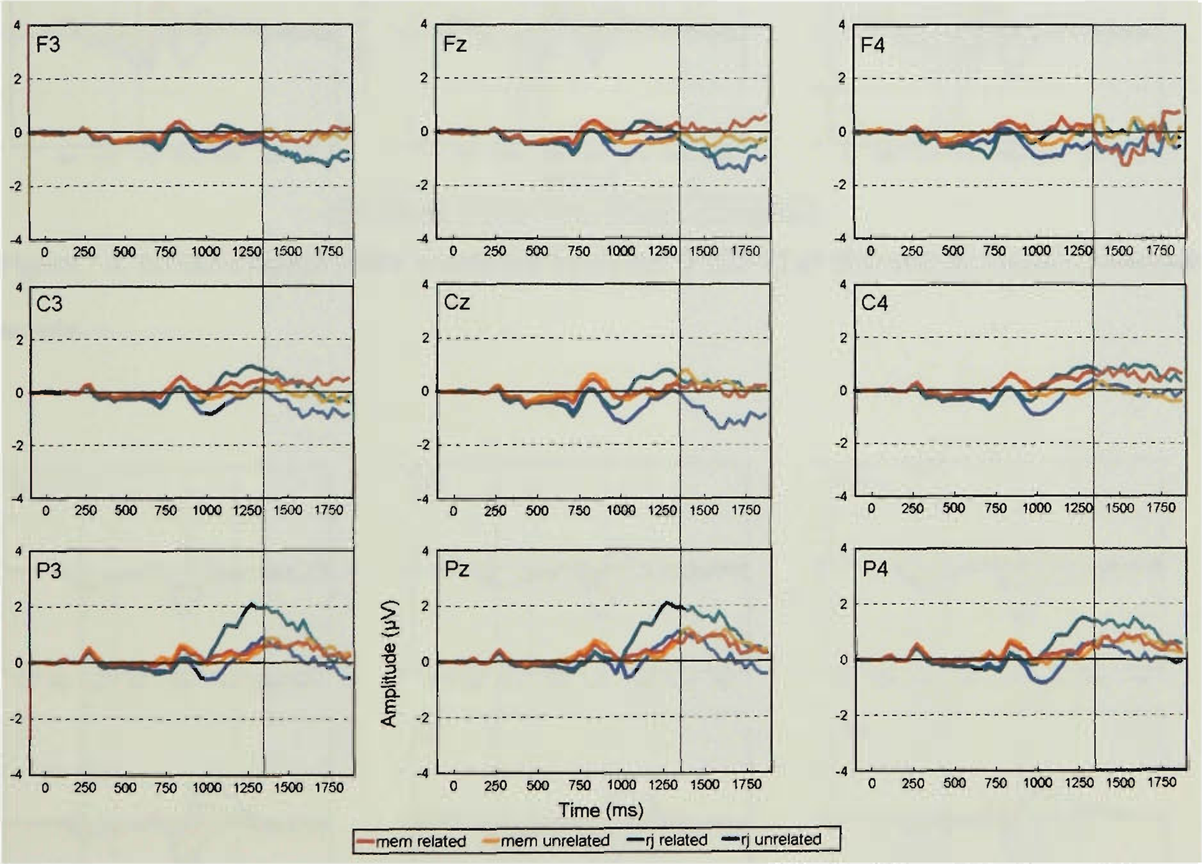


Figure 7.3. Grand average ERPs multiplied by Factor 1 (Slow Wave) of the rotated, rescaled component matrix.

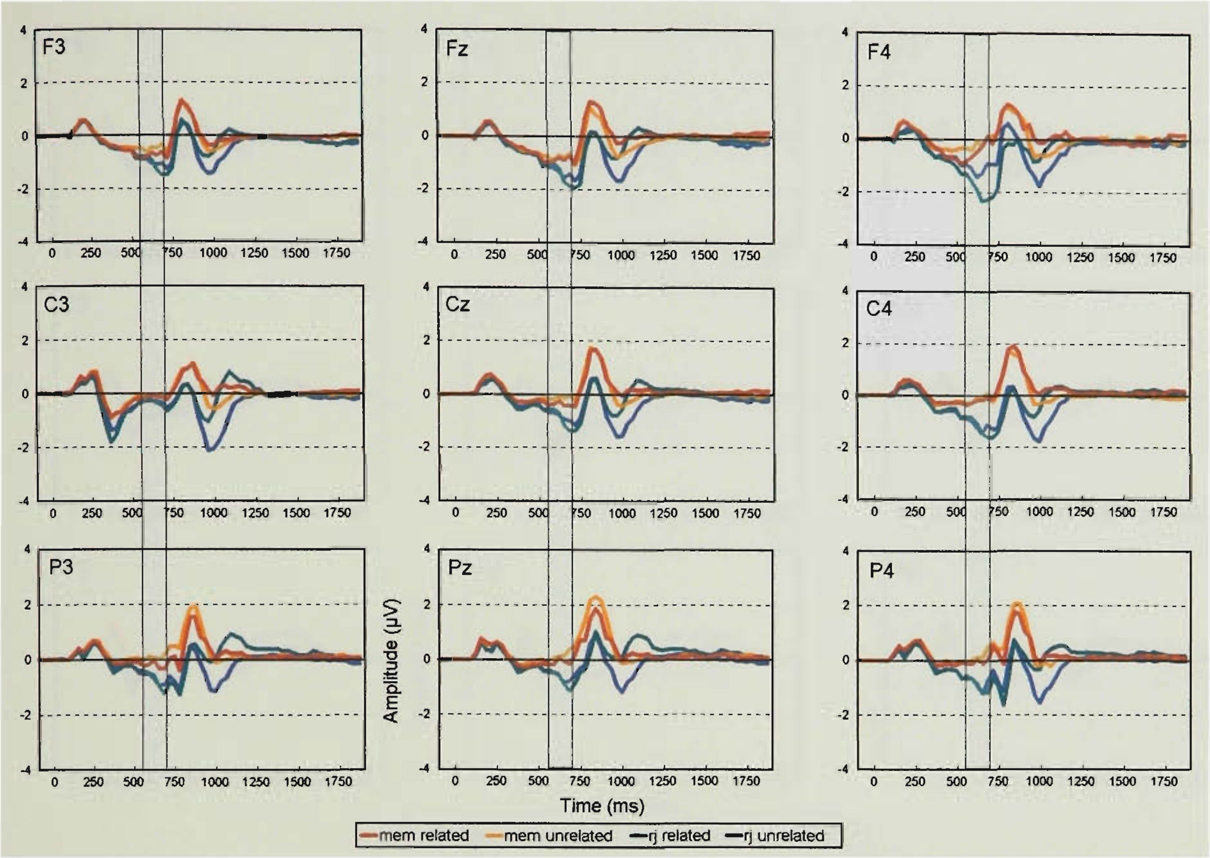


Figure 7.4. Grand average ERPs multiplied by Factor 2 (CNV) of the rotated, rescaled component matrix.

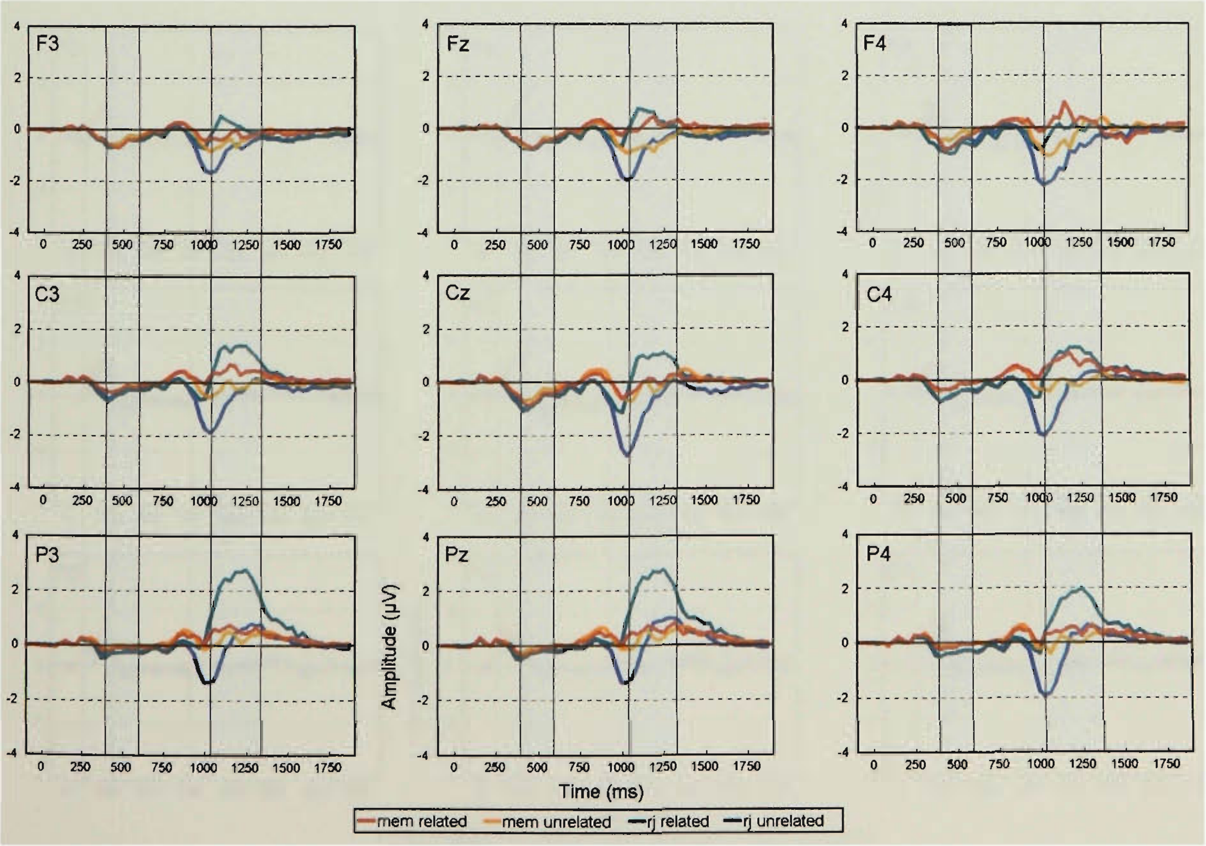


Figure 7.5. Grand average ERPs multiplied by Factor 3 (P3) of the rotated, rescaled component matrix.

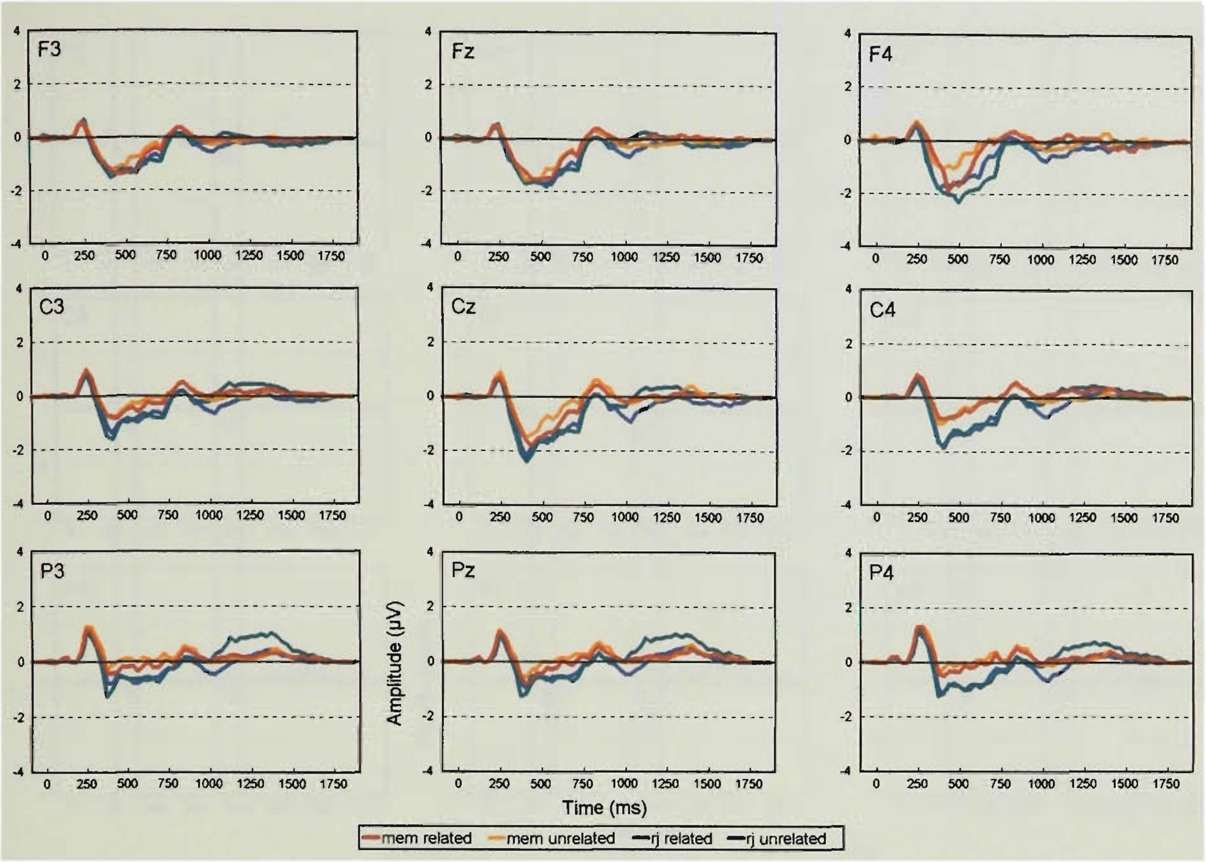


Figure 7.6. Grand average ERPs multiplied by Factor 4 (Unclear) of the rotated, rescaled component matrix.

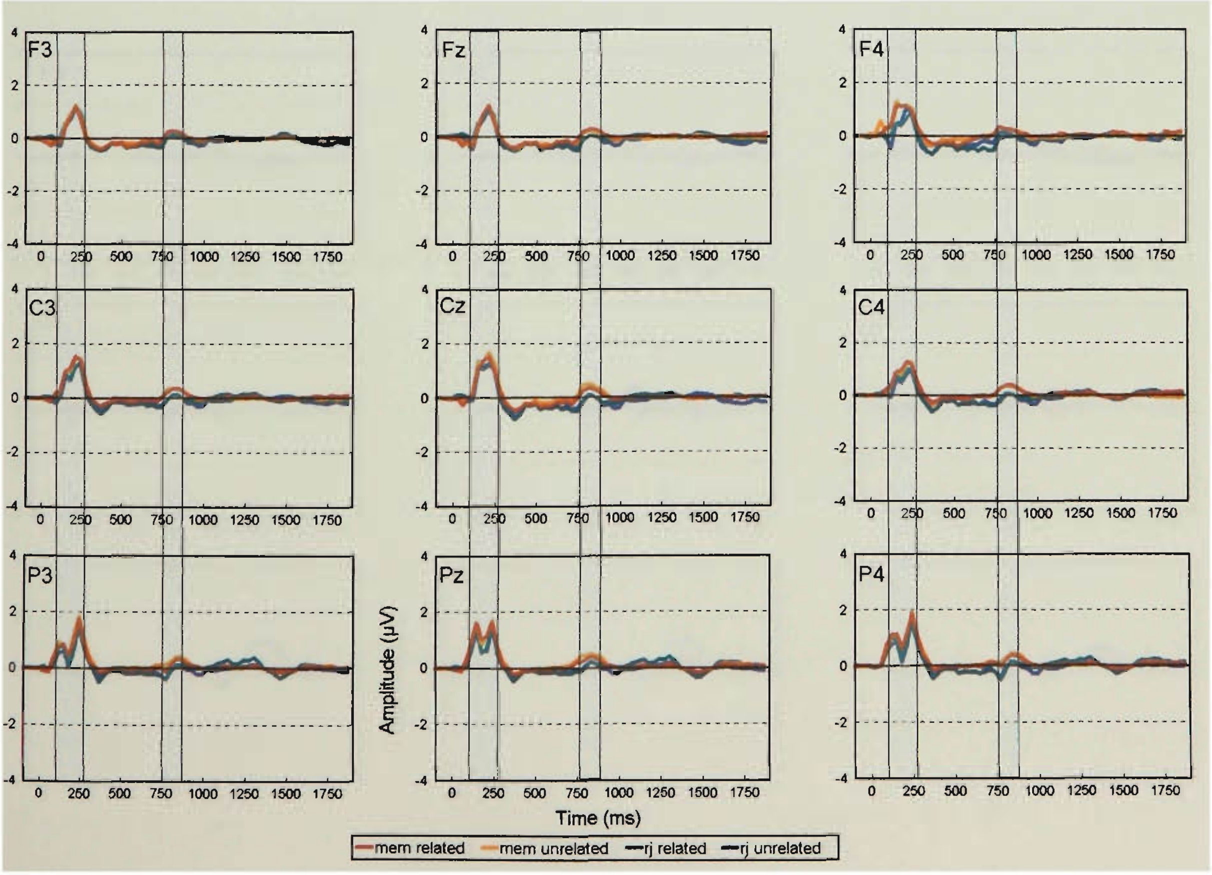


Figure 7.7. Grand average ERPs multiplied by Factor 5 (P2) of the rotated, rescaled component matrix.

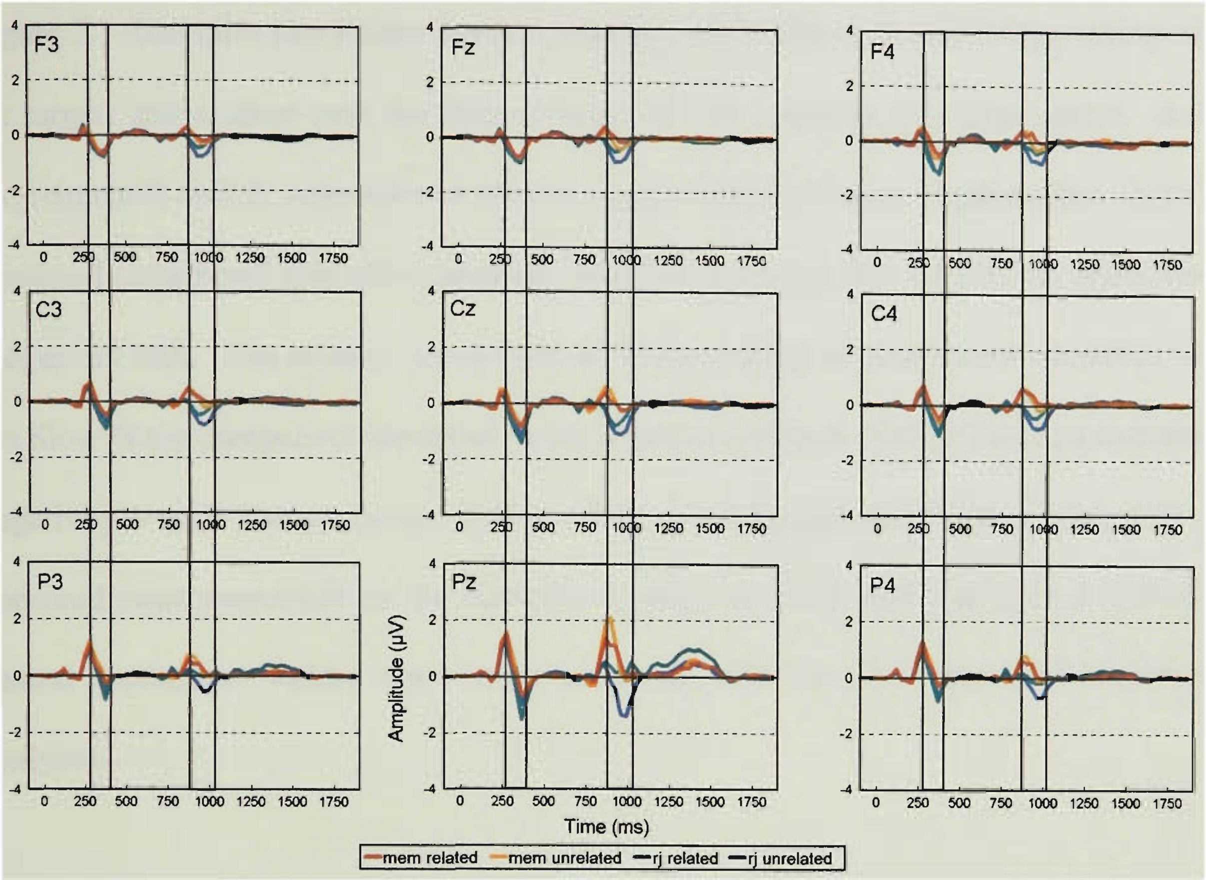


Figure 7.8. Grand average ERPs multiplied by Factor 6 (N400) of the rotated, rescaled component matrix.

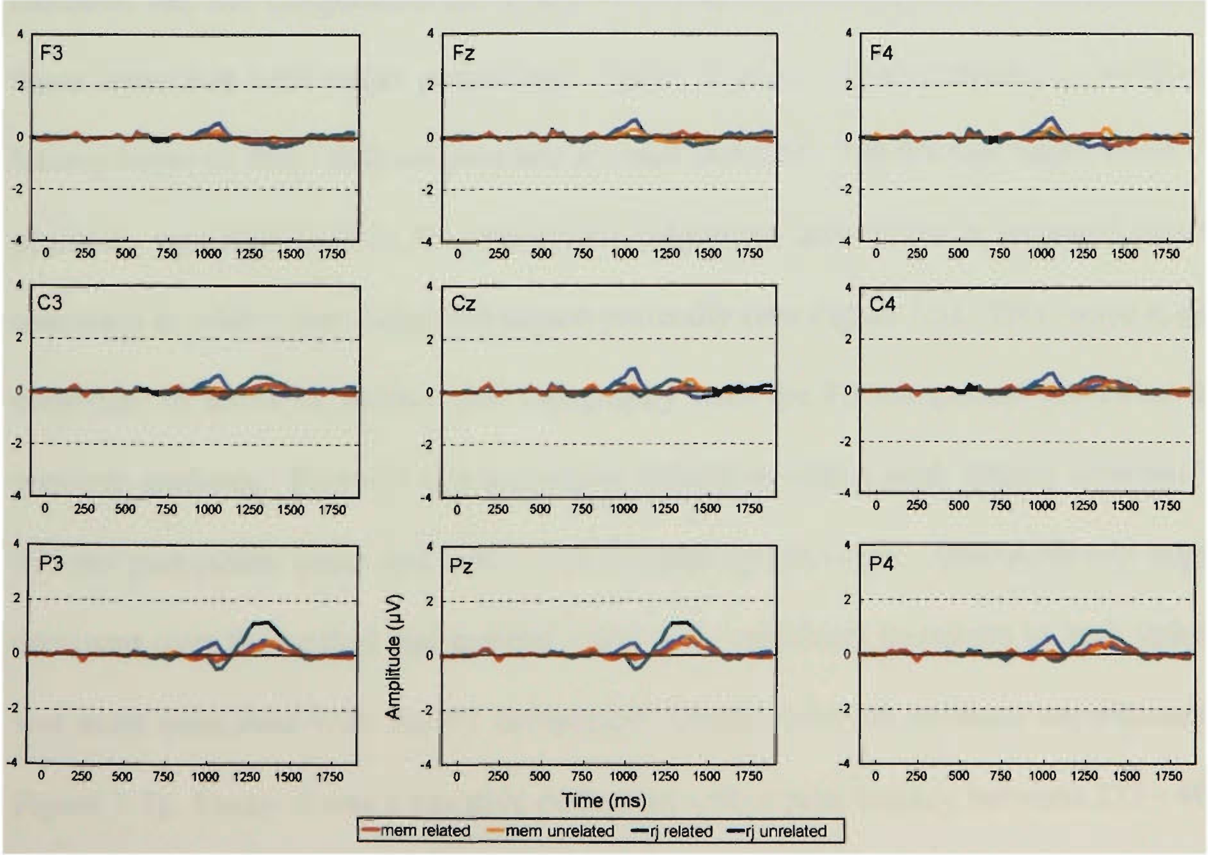


Figure 7.9. Grand average ERPs multiplied by Factor 7 (Unclear) of the rotated, rescaled component matrix.

Figure 7.3 illustrates that Factor 1 was a broadly distributed slow negativity peaking only for targets and evident over the latency range of 200 - 700 ms post target onset. As in Experiment 1 and 2, responses to related targets appeared more negative than those to unrelated targets and this effect appeared maximal centrally, but only in the relatedness-judgement task. The latency, topography and the eliciting stimulus were consistent with the Slow Wave component identified in the previous analyses. Factor 2 was an increasing negativity with a latency range of 600 - 700 ms post-prime onset (see Figure 7.4). It appeared most prominent in the relatedness-judgement task and displayed a frontal to central maximum. Factor 2 was most consistent with the CNV identified in previous analyses.

The PCA clearly indicated that for Factors 3, 5 and 6 there was a single component peak for both prime and target, encompassing a similar latency range after stimulus onset. This indicated that the components associated with prime processing vary in a similar way to those associated with target processing. Factor 4 was a positive deflection with a peak latency between 400 - 600 ms post-prime onset and 620 - 750 ms post target onset. This positivity was dominant in the relatedness-judgement task where it appeared larger for responses to related than unrelated targets parietally (see Figure 7.5). This factor appeared consistent in terms of latency and topography with the P3 component identified in the previous analyses. Factor 5 was a positive deflection with a peak latency between 150 - 275 ms post-prime onset and 150 - 275 ms post target onset. This positivity appeared dominant over the central and parietal regions for responses to primes in both tasks, and was most consistent with the P2 component identified in the previous experiments (see Figure 7.7). Factor 6 was a negative deflection with a peak latency between 275 - 400 ms post-prime onset and 275 - 420 ms post target onset. It was larger for target words

preceded by a semantically-unrelated word compared to when the target was preceded by a semantically-related word (see Figure 7.8). This relatedness effect was predominantly in the relatedness-judgement task, where it displayed a centro-parietal midline topography, commonly associated with the N400 component (Bentin, McCarthy, & Wood, 1985). This relatedness effect also appeared to occur in the memorisation task over the frontal region. The negative deflection described was most consistent with the N400 component identified in the previous experiments. These results confirmed that the underlying systematic variation across site and the effects of the remaining experimental variables is broadly similar for both prime and target. Factors 4 and 7 were not readily identifiable and will not be discussed further.

7.3.4. ERP DATA

The result section will describe the components in the following order where appropriate: P2, N400, P3, CNV, Slow Wave.

7.3.4.1. P2

Across conditions, the P2 was larger over the midline region (1.07 μV) than for the mean of the left and right hemisphere (0.84 μV) [$F = 6.40$, $p < 0.05$]. In the right hemisphere the P2 was larger parietally (0.83 μV) than frontally (0.60 μV), with the effect reversed and smaller in the left hemisphere (0.70 μV and 0.86 μV respectively) [$F = 4.75$, $p < 0.05$]. The P2 was larger parietally than frontally and this difference was large over the midline region (0.58 μV) whilst almost zero for the mean of the left and right hemisphere (0.03 μV) [$F = 15.19$, $p < 0.001$]. The P2 was larger centrally than for the mean of the frontal and parietal sites and the difference was larger in the left (0.40 μV) than the right hemisphere (0.17 μV) [$F = 13.22$, $p < 0.01$]. Overall the P2 displayed a

central-left to parietal-midline topography.

Over the entire scalp, the P2 was larger for the memorisation task (1.37 μV) than for the relatedness-judgement task (0.46 μV) [$F = 8.60$, $p < 0.01$]. It was also larger centrally (1.60 μV) than for the mean of the frontal and parietal sites (1.25 μV) for the memorisation task compared with the relatedness-judgement task (0.52 μV and 0.44 μV respectively) [$F = 11.40$, $p < 0.01$]. That is, the P2 was larger in the memorisation task and this effect displayed a central topography.

Across the scalp, primes (1.38 μV) elicited a larger P2 than targets (0.46 μV) [$F = 10.00$, $p < 0.01$]. The difference between prime and target responses was larger parietally (1.14 μV) than frontally (0.80 μV) for the mean of the left and right hemispheres, with the effect reversed and smaller over the midline (0.62 μV and 0.90 respectively) [$F = 81.31$, $p < 0.001$]. The difference was also larger centrally (1.25 μV) than for the mean of the frontal and parietal sites (0.76 μV) over the midline region, with the effect reversed and more equipotential for the mean of the left and right hemispheres (0.83 μV and 0.97 μV respectively) [$F = 29.50$, $p < 0.001$]. Overall, the P2 was larger to primes than targets, and the difference displayed a parietal-left to central-midline topography.

For the relatedness-judgement task, the P2s elicited by primes were larger than target responses and this difference was larger centrally (2.07 μV) than for the mean of the frontal and parietal sites (1.32 μV) over the midline region, with the effect reversed but more equipotential for the mean of the left and right hemispheres (1.45 μV and 1.50 μV respectively). However, the difference between prime and target P2s for the memorisation task was much smaller and more equipotential overall (central midline: 0.41

μV, frontal/parietal midline: 0.20 μV, central left/right: 0.22 μV, frontal/parietal left/right: 0.44 μV) [$F = 9.35$, $p < 0.01$]. That is, the P2 was larger for prime than target responses and the difference was larger in the relatedness-judgement task, where it displayed a central-midline topography, relative to the memorisation task in which it was more equipotential.

7.3.4.2. N400

The N400 was larger frontally (-0.79 μV) than parietally (0.32 μV) [$F = 10.42$, $p < 0.01$] and larger over the midline region (-0.55 μV) than for the mean of the left and right hemispheres (-0.28 μV) [$F = 7.24$, $p < 0.05$]. It was also larger centrally (-0.63 μV) than for the mean of the frontal and parietal sites (-0.24 μV) [$F = 12.22$, $p < 0.01$] and the difference was larger over the midline region (0.97 μV) compared with the mean of the left and right hemispheres (0.23 μV) [$F = 32.07$, $p < 0.001$]. Overall, the N400 displayed a frontal to central-midline topography.

The N400 was larger in the relatedness-judgement task (-0.89 μV) than the memorisation task (0.16 μV) [$F = 13.41$, $p < 0.01$]. It was larger centrally (-1.33 μV) than for the mean of the frontal and parietal sites (-0.67 μV) in the relatedness-judgement task, compared with the memorisation task (0.06 μV and 0.20 μV respectively) [$F = 33.17$, $p < 0.001$]. That is, the N400 was larger in the relatedness-judgement task and displayed a central topography, compared with the memorisation task, where it was virtually absent.

The N400 was larger over the midline region than the mean of the left and right hemispheres and the difference was larger for prime responses (0.40 μV) than target

responses (0.14 μV) [$F = 17.70$, $p < 0.001$]. The N400 was also larger frontally than parietally and this difference was larger in the right hemisphere (1.40 μV) than the left hemisphere (1.33 μV) for prime responses. For target responses the effect was smaller and reversed, being larger in the left hemisphere (1.02 μV) than the right hemisphere (0.67 μV) [$F = 14.53$, $p < 0.01$]. The frontal-parietal difference was also larger for the mean of the left and right hemispheres (1.37 μV) than the midline (1.18 μV) for prime responses compared with a smaller, reversed effect for target responses (0.85 μV and 1.09 μV respectively) [$F = 22.37$, $p < 0.001$]. The N400 was larger centrally than for the mean of the frontal and parietal sites and this difference was larger in the right hemisphere (0.38 μV) than the left hemisphere (0.20 μV) for prime responses; for target responses the effect was smaller and reversed (0.12 μV and 0.21 μV respectively) [$F = 7.18$, $p < 0.05$]. That is, the N400 was larger to primes and displayed a fronto-central right topography, whilst to targets it displayed a fronto-central left topography.

The N400 elicited by unrelated targets (-0.61 μV) was larger than related targets (-0.11 μV), with the effect reversed and more equipotential for primes associated with unrelated (-0.30 μV) and related (-0.46 μV) targets [$F = 6.89$, $p < 0.05$]. The relatedness-judgement task elicited a larger N400 than the memorisation task and it was larger for targets (-1.15 μV) than primes (-0.64 μV), with the reverse in the memorisation task (0.42 μV and -0.11 μV respectively) [$F = 6.93$, $p < 0.05$]. In the relatedness-judgement task, unrelated targets elicited a larger N400 than related targets and this difference was larger parietally (0.97 μV) than frontally (0.80 μV), compared with the memorisation task, in which it was larger frontally (0.44 μV) than parietally (0.11 μV). The difference in prime responses associated with related and unrelated targets was far more equipotential

for both tasks (relatedness-judgement: frontal 0.02 μV, parietal 0.06 μV; memorisation: frontal 0.04, parietal 0.07 μV) [$F = 5.01$, $p < 0.05$]. Across sites, the N400 to related targets was larger than that to unrelated targets, that is, priming occurred. Overall, primes elicited a larger N400 than targets and this displayed a fronto-central right topography. Over the entire scalp, the N400 elicited by targets was larger than that to primes in the relatedness-judgement task, with the reverse occurring in the memorisation task.

7.3.4.3. P3

The P3 was larger parietally (0.10 μV) than frontally (-1.09 μV) [$F = 12.83$, $p < 0.01$]. The parietal-frontal difference was maximal over the midline region (1.36 μV) compared with the mean of the left and right hemispheres (1.10 μV) [$F = 5.92$, $p < 0.05$]. P3 was also larger for the mean of the frontal and parietal sites (-0.47 μV) than central sites (-1.10 μV) over the midline region, with the effect reversed and almost equipotential for the mean of the left and right hemispheres (-0.51 μV and -0.48 μV) [$F = 68.06$, $p < 0.001$]. That is, P3 displayed a parietal midline topography.

The P3 was somewhat larger in the left hemisphere than the right hemisphere and this difference was larger in the relatedness-judgement task (0.31 μV) than in the memorisation task (0.01 μV) [$F = 7.81$, $p < 0.05$]. P3 was also larger for the mean of the frontal and parietal sites than the central sites and the difference was larger in the relatedness-judgement task (0.36 μV) than the memorisation task (0.02 μV) [$F = 16.69$, $p < 0.001$]. The P3 displayed a left-hemisphere to parietal distribution in the relatedness-judgement task but these effects were almost absent for the memorisation task.

The P3 was larger for related than unrelated words and the difference was larger parietally

(0.71 μV) than frontally (0.24 μV) in the left hemisphere but almost equipotential in the right hemisphere (0.66 μV and 0.63 μV respectively) [$F = 13.11$, $p < 0.01$]. That is, P3 was larger for responses to related than unrelated words and displayed a left-parietal distribution.

Over the entire scalp, targets (0.19 μV) elicited a larger P3 than primes (-1.31 μV) [$F = 26.22$, $p < 0.001$]. Primes elicited a larger P3 in the mean of the left and right hemispheres (-1.18 μV) than the midline (-1.56 μV), compared with target responses, which were equipotential (0.19 μV and 0.19 μV respectively) [$F = 25.04$, $p < 0.001$]. The P3 was larger parietally than frontally and this difference was larger in the left (1.55 μV) than the right hemisphere (0.82 μV) for target responses, with a smaller effect for prime responses (1.04 μV and 0.98 μV) [$F = 15.32$, $p < 0.001$]. For target responses the P3 was larger over the central region (0.24 μV) than the mean of the frontal and parietal sites (0.09 μV) in the right hemisphere compared with the left hemisphere, where it was equipotential (0.24 μV and 0.24 μV respectively). In contrast, the P3 was almost equipotential for primes, slightly larger for the mean of the frontal and parietal sites (-1.26 μV) than the central site (-1.34 μV) in the right hemisphere, with the reverse in the left hemisphere (-1.05 μV and -1.09 μV respectively) [$F = 9.17$, $p < 0.01$]. Overall, the P3 was larger for targets and displayed a left-parietal to right-central topography, relative to prime responses which displayed a left-parietal topography.

Over the entire scalp, the P3 was larger for targets than primes and this difference was larger in the relatedness-judgement task (1.91 μV) than the memorisation task (1.08 μV) [$F = 5.45$, $p < 0.05$]. P3 was larger for targets than primes and the difference was larger

parietally (2.29 μV) than frontally (1.51 μV) in the relatedness-judgement task, with a smaller reverse effect in the memorisation task (0.79 μV and 1.24 μV respectively) [$F = 7.74$, $p < 0.05$]. Overall, P3 was larger in the relatedness-judgement task for targets than primes and the difference displayed a parietal topography, with a smaller reversed-topography effect in the memorisation task.

Over the entire scalp, related targets elicited a larger P3 (0.88 μV) than unrelated targets (-0.48 μV), with a smaller reverse effect for related and unrelated primes (-1.40 μV and -1.24 μV respectively) [$F = 17.45$, $p < 0.001$]. For targets, related words elicited a larger P3 than unrelated words and the difference was larger parietally (1.62 μV) than frontally (0.72 μV) in the left hemisphere compared with the right hemisphere (1.44 μV and 1.28 μV respectively). Primes elicited a larger P3 for unrelated than related words but the difference was far more equipotential (frontal left: 0.24 μV, parietal left: 0.21 μV; frontal right: 0.03μV, parietal right: 0.13 μV). [$F = 18.13$, $p < 0.01$]. That is, P3 was larger for related than unrelated target responses and displayed a left-parietal topography compared with prime responses which were much more equipotential.

Across sites, related targets elicited a larger P3 than unrelated targets and the difference was much larger in the relatedness-judgement task (2.05 μV) than the memorisation task (0.64 μV), with the effect reversed but far more equipotential for prime responses (0.02 μV and 0.27 μV respectively) [$F = 5.24$, $p < 0.05$]. Over the entire scalp, the P3 was larger for related than unrelated targets and the difference was larger in the relatedness-judgement task than the memorisation task, with prime responses much smaller in both tasks.

7.3.4.4. CNV

The CNV was more negative for the frontal (-1.44 μV) than the parietal region (-0.64 μV) [F = 4.68, p < 0.05] and over the midline region (-1.24 μV) than for the mean of the left and right hemispheres (-1.01 μV) [F = 6.05, p < 0.05]. The frontal-parietal difference was larger over the midline region (1.09 μV) than the mean of the left and right hemispheres (0.65 μV) [F = 23.38, p < 0.001]. Similarly, the CNV was larger centrally (-1.61 μV) than for the mean of the frontal and parietal sites (-1.05 μV) over the midline region, with the effect weakly reversed (almost equipotential) for the mean of the left and right hemispheres (-0.95 μV and -1.04 μV respectively) [F = 47.96, p < 0.001]. That is, the CNV displayed a fronto-central midline topography.

The CNV was larger in the relatedness-judgement task (-1.67 μV) than the memorisation task (-0.50 μV) [F = 9.76, p < 0.01]. The CNV was more negative in the right (-1.79 μV) than the left hemisphere (-1.40 μV) for the relatedness-judgement task, with the effect reversed and far more equipotential in the memorisation task (-0.38 μV and -0.48 μV respectively) [F = 9.92, p < 0.01]. That is, the CNV was larger in the relatedness-judgement task and displayed a right-hemisphere maximum, relative to the memorisation task, in which it was more equipotential.

7.3.4.5. Slow Wave

The Slow Wave was more negative in the frontal region (-0.47 μV) than the parietal region (0.85 μV) [F = 19.72, p < 0.001]. The Slow Wave was also more negative centrally (-0.04 μV) than for the mean of the frontal and parietal sites (0.27 μV) over the midline region, compared with the mean of the left and right hemispheres (0.22 μV versus

0.15 μV respectively) [$F = 18.37$, $p < 0.001$]. Overall, the Slow Wave displayed a negativity that was largest frontally and over the central-midline region.

The Slow Wave was larger for unrelated responses than related responses and this difference was larger centrally (0.67 μV) than for the mean of the frontal and parietal sites (0.40 μV) but the effect only approached significance [$F = 5.16$, $p = 0.058$].

7.3.5. SUMMARY

Where applicable, this section will summarize the topography of the ERP components.

7.3.5.1. ACROSS CONDITIONS

The P2 was maximal over the central left and parietal midline regions. N400 displayed a frontal to central midline topography. P3 was maximal parietally in the left hemisphere.

7.3.5.2. WORD TYPE

Overall, the P2 was larger for primes than targets and the difference displayed a left-parietal to midline-central topography. N400 prime responses were larger and displayed a right fronto-central topography, relative to N400 target responses, which were more equipotential with a left fronto-central to midline frontal maximum. The P3 was larger in responses to targets and displayed a left-parietal to right-central topography relative to prime responses, which displayed a left-parietal topography. The CNV occurred only to the prime and displayed a midline fronto-central topography. The negative Slow Wave, which followed only the target, was maximal over the frontal and midline-central regions.

7.3.5.3. RELATEDNESS

The P3 elicited by related words was larger than to unrelated words; this difference displayed a left parietal topography. Unrelated words elicited a larger Slow Wave than related words, a difference maximal over the vertex. However, this effect only approached significance.

7.3.5.4. TASK

The P2 was larger in the memorisation task and was maximal over the central region, compared with the relatedness-judgment task, in which it was more equipotential. Over the entire scalp, the N400 was larger in the relatedness-judgement task and displayed a central maximum; in the memorisation task it displayed similar topography but was smaller and more equipotential. The P3 displayed a left-hemisphere to parietal maximum in the relatedness-judgement task, but was equipotential in the memorisation task.

7.3.5.5. WORD TYPE X TASK

Primes in the relatedness-judgement task elicited a larger P2 than targets and the difference displayed a vertex topography, whereas responses to primes and targets in the memorisation task were more equipotential. Across all sites, target and primes in the relatedness-judgement task elicited a larger N400 than in the memorisation task; responses to targets were larger than to primes in the relatedness-judgement task, with the reverse in the memorisation task. Over the entire scalp, the positivity associated with the P3 was larger for targets than primes and the difference was larger in the relatedness-judgement task than the memorisation task. P3 to targets in the relatedness-judgement task displayed a parietal topography; the P3 was also larger parietally for responses to primes in the memorisation task, but responses to primes and targets were almost

equipotential parietally. The CNV, elicited only by the prime, was larger in the relatedness-judgement task and displayed a right-hemisphere maximum, whereas in the memorisation task it displayed a small left- hemisphere maximum.

7.3.5.6. WORD TYPE X RELATEDNESS

Across all sites, unrelated targets elicited a larger N400 than related targets, with the effect almost absent in the responses to primes. Over the entire scalp, related targets elicited a larger P3 than unrelated targets, whereas responses to primes were far more equipotential. P3 to related targets displayed a left-parietal topography, whereas prime responses were almost equipotential.

7.3.5.7. WORD TYPE X TASK X RELATEDNESS

Responses to targets demonstrated a priming effect on N400 amplitude, that is, the N400 was larger for responses to unrelated than related targets. This effect was larger in the relatedness-judgement task and displayed a parietal topography, whereas the effect was smaller and frontal in the memorisation task. Responses to the preceding unrelated and related primes were almost equipotential for both tasks. Over the entire scalp, the P3 elicited by related targets was larger than that to unrelated targets and this difference was larger in the relatedness-judgement task than the memorisation task. The responses to unrelated and related primes were equipotential for both tasks over the P3 latency range used.

7.4. DISCUSSION

7.4.1 BEHAVIOURAL ASPECTS

In the relatedness-judgement task, responses to related targets were significantly faster

than those to unrelated targets. The memorisation task also displayed a priming effect, with better recognition for related than unrelated word pairs that were previously presented. That is, both tasks displayed a priming effect for behavioural measures.

7.4.2. CNV

Contingent negative variation is usually associated with a frontal topography and late onset (Hillyard, as cited in McCallum & Knott, 1973; Holcomb, 1988; Rohrbaugh & Gaillard, as cited in Gaillard & Ritter, 1983; McCallum, as cited in Desmedt, 1979). Across conditions the slow negativity emerging after presentation of the prime words displayed a midline fronto-central topography consistent with CNV. This CNV was larger in the relatedness-judgement task and displayed a right-hemisphere topography; it was far smaller in the memorisation task and displayed a weak left-hemisphere topography. The topography of this interaction was not consistent with the frontal topography usually associated with this component. If it is assumed that the CNV reflects cognitive processing associated with the preparation or anticipation of a stimulus event, then the difference in the topography and magnitude of the CNV between the two tasks may reflect differential processing of the primes or, more likely, differential preparatory activities prior to the target (Donchin, Gerbrandt, Leifer, & Tucker, 1972; Hillyard, as cited in McCallum & Knott, 1973; Holcomb, 1988; McCallum, as cited in Desmedt, 1979; Rohrbaugh & Gaillard, as cited in Gaillard & Ritter, 1983). The relatedness-judgement task required an immediate response based on the relationship between the prime and target, and this is reflected in the greater preparatory processing between prime and target in the relatedness-judgement task compared with a virtual absence of such processing in the memorisation task. It should be noted that in the relatedness-judgement task subjects were explicitly instructed to attend to the semantic relationship between the word-pairs

presented, whereas subjects were not told of any relationship between words in the memorisation task. Similarly, in Experiment 2, where primes in the silent-reading task did not generate a CNV, the relationship between the first and second word was not crucial to performing the task nor were the subjects explicitly instructed to attend to any relationship between words.

7.4.3. P2

P2 displayed a peak latency between 150 - 275 ms post-prime onset and 150 - 275 ms post target onset. Across conditions the P2 was larger over the left-central and midline-parietal regions and is consistent with the literature (Luck & Hillyard, 1994; McDonough, Warren, & Don, 1992; Raney, 1993). This component has been associated with short-term memory storage (Chapman, McCrary, & Chapman, 1981; Friedman, Vaughan, & Erlenmeyer-Kimling, 1981). Over the entire scalp, the P2 was larger in responses to primes than targets and the difference displayed a left-parietal to midline-central topography. P2 was larger in the memorisation task and displayed a central topography, with a more-equipotential outcome in the relatedness-judgement task. The P2 elicited by primes was larger than that to targets in the relatedness-judgement task and the difference displayed a central-midline topography, whereas responses to primes and targets in the memorisation task were more equipotential. No significant semantic priming effects were obtained for this component. The results are consistent with previous interpretations of the P2 component, which have associated it with early processes of sensory encoding (Luck & Hillyard, 1994). Whilst the lack of a priming effect on P2 amplitude is consistent with the findings in the letter-search task (Experiment 1) and the silent-reading task (Experiment 2), it is at odds with the results of the same type of relatedness-judgement task used in Experiment 2, and this will be discussed further in the Conclusion.

7.4.4. N400

The N400 occurred in response to both prime (275 ms - 400 ms) and target (275 ms - 420 ms) over a similar time frame after stimulus onset and within the one factor, as indicated by the PCA. The N400 displayed a frontal to vertex topography across conditions. It was larger in prime than target responses centrally. This may reflect an attenuation of N400 amplitude in response to related targets which reduces the average size of target responses overall. The N400 was larger in the relatedness-judgement task than the memorisation task. In the relatedness-judgement task it displayed a central maximum, but it was almost equipotential in the memorisation task. An ERP priming effect was evident over the interval 275 ms - 420 ms post target onset. Targets showed a priming effect on N400 amplitude in both tasks. This effect was larger in the relatedness-judgement task and displayed a traditional parietal topography. The latency, topography and sensitivity of this ERP component to semantic priming was consistent with the N400 component reported in research using similar paradigms (Bentin, 1987; Bentin et al., 1985; Brown & Hagoort, 1993; Holcomb, 1988, 1983; Kutas & Hillyard, 1980a, 1980b, 1982, 1989; McCarthy & Nobre, 1993; Young & Rugg, 1992). The priming effect in the memorisation task displayed a frontal topography characteristic of such a task (Bentin, Kutas, & Hillyard, 1993; Bentin, McCarthy, & Wood, 1984). It is interesting to note that the N400 effect obtained in the relatedness-judgement task in Experiment 2 displayed a vertex maximum compared to the parietal maximum obtained using a similar task in this experiment.

7.4.5. P3

The P3 also occurred within the one factor for both prime (400 ms - 600 ms) and target (420 ms - 750 ms). The P3 was larger in the relatedness-judgement task and displayed a left-hemisphere to parietal topography compared with that in the memorisation task,

where it was equipotential. The P3 typically displays a centro-parietal topography, but the current results show a left-hemisphere to parietal topography. P3 is commonly elicited in tasks that require stimulus evaluation and is largest when the response to task-relevant stimuli is overt and immediate (Bentin, 1987; Bentin et al., 1985; Donchin & Coles, 1988; Herning et al., 1987; Neville et al., 1986; Rugg, 1987), as was the case in the relatedness-judgement task. The memorisation task required stimulus evaluation, but no overt or immediate response was required, resulting in an attenuation or elimination of the P3 component (Kutas & Hillyard, 1980, 1982, 1983, 1984; Rugg, 1987). Overall, the P3 was larger for responses to targets than primes in the relatedness-judgement task compared with the memorisation task. Target responses were maximal over the parietal region in the relatedness-judgement task. The P3 elicited by related targets was larger than that to unrelated targets and displayed a left-parietal topography, whereas responses to primes were almost equipotential for related and unrelated word pairs. The priming effect was predominant in the relatedness-judgement task across the entire scalp, whereas the effect was almost absent in the memorisation task. The predominance of the priming effect in the relatedness-judgement task suggests that the P3 was sensitive to the manipulation of semantic information. However, the broad distribution of the priming effect was not consistent with the typical centro-parietal maximum obtained in a similar task used in Experiment 2.

7.4.6. SLOW WAVE

Across conditions, the Slow Wave displayed a frontal to vertex topography, which is generally consistent with the frontal topography commonly associated with this component (Holcomb, 1988; McCallum, as cited in Desmedt, 1979). A negative Slow Wave with frontal topography has been associated with the active retrieval of semantic

information from long-term memory (Rösler, Heil, & Glowalla, 1993; Uhl et al., 1990). However, semantic priming effects only approached significance for this component, which is again inconsistent with the findings in Experiments 2. It should be noted that, as in Experiment 2, the priming effect on Slow Wave amplitude (unrelated > related) was opposite to that obtained in Experiment 1 (related > unrelated).

7.4.7. COMPONENT OVERLAP

This section will re-visit the issue of whether the priming effect on N400 amplitude elicited by target words in the relatedness-judgement task could be attributed to component overlap with the P3 effects. As mentioned in the previous experiment, differences in N400 amplitude may be confounded by an increase in P3 amplitude and/or shortened latency (Boddy, 1986; Chwilla, Hagoort, & Brown, 1998). The approach to this issue will be the same as that in the previous experiment: an effect of relatedness due solely to another component should have the same topography. The focus will be on topographic differences and similarities between the N400 and P3 components, as no other components displayed a semantic priming effect.

- For the variable of 'relatedness' alone, there was no main effect or topographic interactions for the N400, but the P3 displayed a priming effect with a left-parietal maximum.
- For the interaction between 'word type' and 'relatedness', the N400 displayed a priming effect for target responses across the entire scalp. A priming effect on P3 amplitude was also obtained for target responses, but this effect was maximal in the left hemisphere parietally.
- Finally, for the interaction between 'word type', 'task' and 'relatedness', the N400

displayed a parietally-distributed priming effect for responses to targets in the relatedness-judgement task, and the effect was smaller and frontal for the memorisation task. The P3 also displayed a priming effect for responses to targets in the relatedness-judgement task, but the effect was evenly distributed over the entire scalp; the effect was almost absent in the memorisation task.

The disparity in the topography of these priming effects on N400 and P3 amplitudes suggests that these effects emerged independently in each component. This conclusion is supported by the priming effect on N400 amplitude obtained for target responses in the memorisation task, a task in which the P3 was almost absent. This is consistent with previous findings that have reported a semantic priming effect on N400 amplitude for single words in the absence of an overt immediate response commonly associated with P3 (Bentin, Kutas, & Hillyard, 1993; Bentin, McCarthy, & Wood, 1984).

7.5. CONCLUSION

As in Experiment 2, the response components identified in this experiment, using PCA, were P2, N400, P3, CNV, and the Slow Wave. Of these, the P2, N400 and P3 components again reflected underlying cognitive processes associated with the processing of the prime that are not distinct from those used to process the target.

This experiment used a multi-tasking approach in the visual modality to assess ERP indices of semantic processing between two consecutively-presented words, particularly the N400 component.

The priming effect on N400 amplitude was larger in the relatedness-judgement task and

displayed a parietal topography, compared with the memorisation task, in which it displayed a frontal topography. The difference in the magnitude of the priming effect between tasks may reflect the subjects' reduced awareness of semantic relationships in the memorisation task due to task instruction (Bentin, Kutas, & Hillyard, 1993). This is consistent with the literature and the findings of the previous experiment, implicating the magnitude of the priming effect on N400 amplitude with the extent to which the task encouraged subjects to attend and utilise semantic information. (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Deacon, Breton, Ritter, & Vaughan, 1991; Kellenbach & Michie, 1996; Rugg, Furda, & Lorist, 1988) The N400 effect is thought to reflect the recognition of semantic expectancy brought about by the integration of word representations with the current context (Federmeier & Kutas, 1999; Weckerly & Kutas, 1999). For example, Bentin et al. (1993) used the N400 component to examine semantic priming effects while manipulating the extent of semantic elaboration required to process primes and targets in the auditory modality. Subjects were required to perform two tasks. In one they had to study a list of words and perform a subsequent recognition test. In the other task, subjects performed a lexical-decision task in which they were required to keep a silent count of nonwords. The N400 priming effect was found to occur only in the memorisation task. They suggested that "the amount of attention directed to semantic analysis appears to be important in determining the size of the N400 priming effect" (p. 167).

It has been suggested that N400s with a frontal distribution reflect word recognition in short-term memory, whilst a posterior distribution reflects elaborative semantic processes in long-term memory (Stelmack & Miles, 1990). Using this interpretation, the frontal distribution of the N400 in the memorisation task may reflect the use of semantic features

in short-term memory, whereas the posterior distribution in the relatedness-judgement task may be associated with elaborative semantic processes in long-term memory.

The presence of the N400 and the semantic priming effects on N400 amplitude in this experiment have similar implications for models of semantic memory as the findings of Experiment 2. Overall, the N400 elicited in the relatedness-judgement task was larger than that in the memorisation task. The N400 elicited by targets was greater than that to primes in the relatedness-judgement task, with the reverse in the memorisation task. The priming effect on N400 amplitude for targets in the relatedness-judgement task was larger than that for targets in the memorisation task. The interaction of task and relatedness implies that the priming effect on N400 amplitude reflected post-lexical processes, possibly associated with expectancy-induced priming and/or semantic matching/integration. That is, the larger priming effect on N400 amplitude in the relatedness-judgement task compared with the memorisation task is not consistent with a truly automatic process, which should be of a similar magnitude regardless of task manipulation. It is important to note that this interpretation hinges on the assumption that spreading activation is an automatic process that conforms to all the characteristics which define such a process. As discussed in Experiment 2, the mere presence of the N400 in the absence of an N400 effect suggests that this effect may stem from task demands which require controlled processing (attention) to monitor and influence an aspect of processing which is usually automatic. The difference in the magnitude of the N400 effect between tasks suggests that the extent of attention directed to monitor such processing varied between tasks. As mentioned previously, Stolz and Besner (1996) suggest that the concept of automaticity becomes redundant in an interactive activation framework because the mind is conceptualised as an interactive system and subjects generate a set

regardless of the task.

In the context of the compound-cue model (Ratcliff & McKoon, 1988), the difference in the priming effect on N400 amplitude between tasks may reflect the extent to which the integrative mechanism joined the prime and target during encoding. There may have been greater activation of the integrative mechanism in the relatedness-judgement task, resulting in a higher familiarity value for related targets, and reflected in the attenuation of N400 amplitude. There may have been less activation of the integrative mechanism in the memorisation task, resulting in a lower familiarity value for related targets, with this being reflected in the smaller priming effect on N400 amplitude.

Priming in the connectionist models emerges because the prime activates semantic patterns associated with related words, and the activation pattern associated with related target words stabilises at a faster rate than that for unrelated target words. The attenuation in N400 amplitude may reflect the faster stabilisation of related word targets. Activation of semantic patterns by primes may have occurred to a greater extent in the relatedness-judgement task than the memorisation task. As a result of this, the larger priming effect on N400 amplitude in the relatedness-judgement task may reflect the activation pattern associated with related target words stabilising at a faster rate than unrelated target words.

The larger priming effect on N400 amplitude in the relatedness-judgement task compared with the memorisation task suggests that activation was task dependent. That is, both tasks engaged the process of integration, as indexed by the priming effect on N400 amplitude (Kellenbach & Michie, 1996), but to a different extent because optimal task performance may have required attention to be focused on different aspects of processing

depending on the given task instructions (Stolz & Besner, 1996; Ziegler, Besson, Jacobs, Nazir & Carr 1997). As described previously, this is conceptualised as 'set' in the interactive activation framework. In this framework, the top-down influence or strategies used in the two tasks control performance by biasing attention to different levels of representation in the network model, and altering the distribution of activation across the network by biasing the gain between levels. The similarities and differences in components within prime and target processing and between the relatedness-judgement task and memorisation task suggests that the 'system' may have been biased by the set adopted in each task to interpret overlapping but different patterns of activation across the network. Some of these similarities and difference in the ERP signatures of both tasks are detailed below.

The P2 was larger in the memorisation task and displayed a central topography, which has been implicated with increased recall in short-term memory tasks (Chapman, McCrary, & Chapman, 1978). The P2 has also been associated with early item encoding (Hackley, Woldorff, & Hillyard, 1990; Luck & Hillyard, 1994). The results suggested that primes and targets were encoded differently in the relatedness-judgement task, which elicited a larger P2 to primes than targets over the central-midline region. However, the early encoding processes associated with the P2 usually display a frontal topography, whereas central and posterior activation has been associated with partial or complete word retrieval from long-term memory (Dun, Dun, Languis, & Andrews, 1998; Garrett-Peters et al., 1994). Since the relatedness-judgement task involved the processing of word pairs, the attenuation of P2 for responses to targets compared with primes may reflect greater efficiency of early encoding processes given that these processes were used in the processing of the prime, as demonstrated by the PCA-based linking of the component in

prime and target responses.

There was a priming effect on N400 amplitude in both tasks, with distinct topographic differences. As mentioned earlier, the memorisation task was associated with a frontal distribution, which may reflect the use of semantic features in short-term memory. The relatedness-judgement task elicited a posterior priming effect, associated with semantic processes in long-term memory (Stelmack & Miles, 1990). The larger priming effect on N400 amplitude in the relatedness-judgement task than the memorisation task reflects the strategy used as a result of task instruction. In the relatedness-judgement task subjects were made aware of the semantic relationship between word pairs and were required to directly use this information to make an immediate response. Task instructions in the memorisation task resulted in a reduced awareness of semantic relationships, possibly contributing to the poor overall rate of recall and reduced priming effect on N400 amplitude. The difference in magnitude and topography of the N400 between tasks implies that the processes underlying the N400 were being used differently.

A priming effect on P3 was elicited only in the relatedness-judgement task, indicating that different processes were used to perform the two tasks. The P3 is typically elicited in tasks that require stimulus evaluation, and the priming effect in the relatedness-judgement task may reflect the use of semantic information in making the necessary response. The CNV was larger in the relatedness-judgement task and almost absent in the memorisation task, indicating differential preparatory processes prior to the target, possibly indicating that, in the memorisation task, subjects adopted a rote strategy during encoding, attempting to remember each word in a more isolated manner. The Slow Wave was elicited by the target in both tasks, and displayed a frontal to vertex topography.

The similarities and differences in the ERP signature of each task mentioned above support the argument that task demands altered the distribution of activation across the network. It can be assumed that multiple sources of linguistic information were activated and the 'system' was biased by the set adopted to perform the task, resulting in overlapping but different patterns of activation across the network.

The multi-tasking approach again confirmed that semantic priming effects are influenced by the nature of the task performed. The extent of semantic integration was modulated by task instructions and was proposed to be the result of the strategy adopted to perform the task. The fact that the magnitude of the priming effect was influenced by the type of task implied that it is due to post-lexical integration processes.

The influence of component overlap on the priming effect on N400 amplitude was addressed by using a memorisation task that invoked a priming effect on N400 amplitude without the overt response requirements usually accompanied by a P3 component. The memorisation task resulted in a priming effect on N400 without eliciting a distinct P3, whereas a priming effect occurred for both the N400 and P3 components in the relatedness-judgement task. This conclusively showed that the priming effect on N400 amplitude may occur independently of the P3 component. The only contentious issue was the frontal topography of the priming effect in the memorisation task, but this was consistent with similar tasks (Bentin, et al., 1984; Bentin et al., 1993; Stelmack & Miles, 1990) and also evident in picture-naming tasks (Stuss, Picton, & Cerri, 1986), category decision tasks (Neville, Kutas, Chesney, & Schmidt, 1986) and lexical decision tasks (Bentin, McCarthy, & Wood, 1985).

An interesting outcome of the current experiment was the inconsistency of the results in the relatedness-judgement task compared with the previous experiment. The tasks were identical, but the number of word pairs presented was reduced in the current experiment. Averaging over fewer trials may have produced different results since various significant effects noted in the previous experiment, such as the priming effect on the Slow Wave amplitude, appeared to approach significance in the current experiment. The other difference between experiments was that the order of presentation of tasks in the current experiment was counterbalanced, which may have resulted in processing being carried on from one task to another. For example, if subjects performed the relatedness-judgement task before the memorisation task, they may have displayed greater awareness of the semantic relationship between word pairs in the subsequent memorisation task, resulting in greater network processing of semantic information which would be reflected in a better recall of presented related target words and a larger priming effect on N400 amplitude.

CHAPTER 8

PCA, DIFFERENCE WAVES AND DESIGN TECHNIQUES

This chapter will discuss the data analytic technique of principal components analysis, and summarise the findings of the experiments in this context. It will then explore the use of difference waveforms to clarify the effects reported. Finally, the varying design techniques used in the current experiments to investigate the processing nature of the N400 component, and issues regarding component overlap, will be discussed.

8.1. PRINCIPLE COMPONENTS ANALYSIS

The factors emerging from the principle components analyses all displayed an ERP wave-form appearance. The use of this technique showed that the N400 and P3 emerged as orthogonal components, implying that the underlying cognitive processes associated with these components were independent. This is important because it helps clarify the controversy regarding the independence of the N400 and P3 priming effect. Beyond this, the major contribution of this thesis was the novel use of PCA in determining whether the processing associated with target words was similar to that for prime words. The following section will summarise the components and associated processing identified for the prime and target in each experiment.

8.1.1. EXPERIMENT 1

This experiment examined ERPs to the first and second word stimuli presented in a letter-search task, in order to determine whether a non-semantic task would elicit a priming effect on N400 amplitude. The components and their respective latency ranges were

identified using PCA, and are shown again in Figure 8.1 below, with each component identified in terms of the PCA-defined latency ranges. This technique showed that P1, P2 and N400 were common to the processing of both the first and second word stimuli, whereas the CNV and Slow Wave were associated solely with the first and second word processing, respectively.

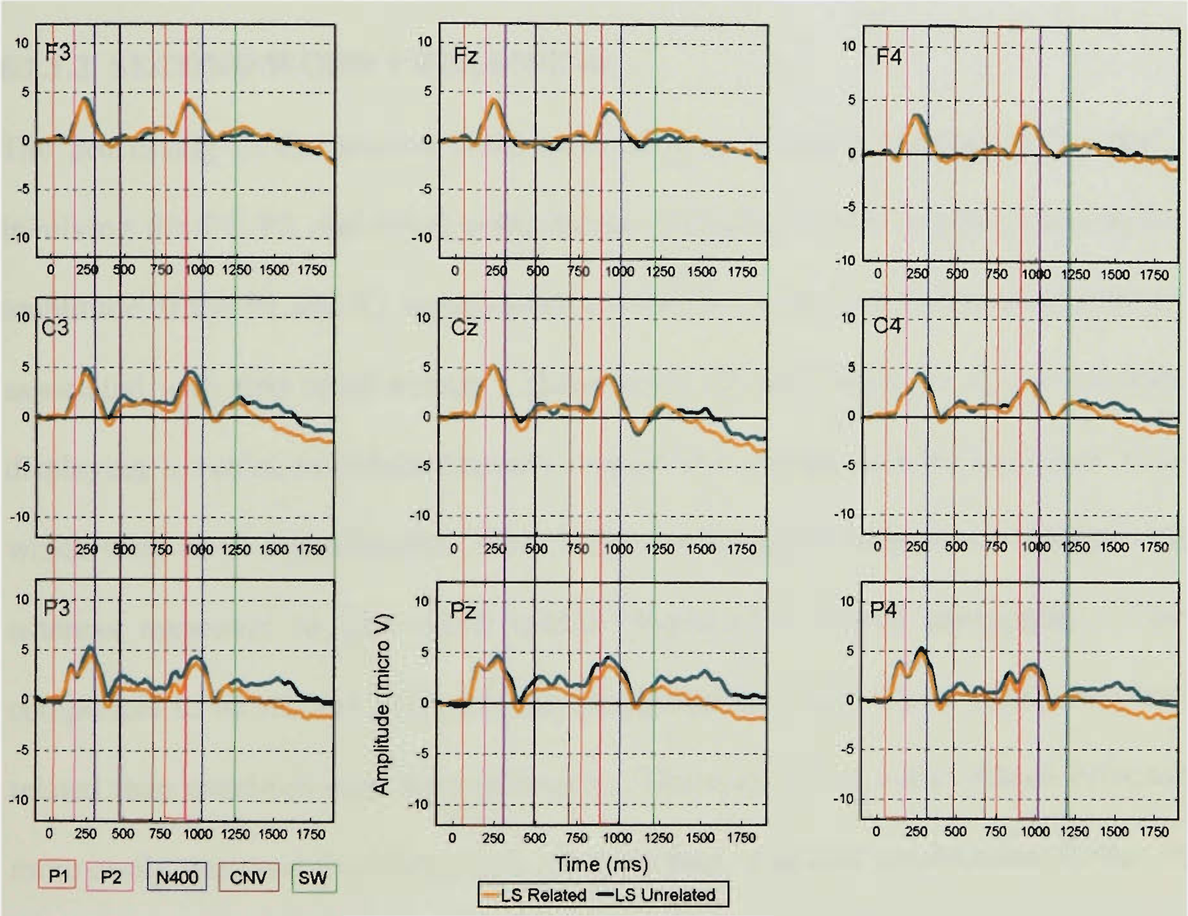


Figure 8.1. Identification of components in the grand average ERPs evoked by the first word and related and unrelated second word stimuli in the letter-search task.

8.1.1.1. FIRST WORD PROCESSING

Figure 8.1 above illustrates a parietally-distributed P1 to the first word, commonly associated with early visuo-spatial attention (Vogel, Luck, & Shapiro, 1998). The following P2 reflects early encoding processes, such as feature detection (Luck & Hillyard, 1994). The subsequent N400 has been associated with lexical-semantic

processes, which covers word-level analysis, including aspects of word meaning activated through semantic representations of word forms (Deacon, Mehta, Tinsley, & Nousak, 1995; Vogel, Luck, & Shapiro, 1998). The CNV was identified only following the first word and reflects preparatory processing which occurs in anticipation of the target (Hillyard, as cited in McCallum & Knott, 1973; Kellenbach & Michie, 1996).

8.1.1.2. SECOND WORD PROCESSING

The processing of the second word proceeded in a similar manner to the first word, involving the P1, P2 and N400 components. However, there is attenuation in the peak amplitude of the P1 and P2 components elicited by second word stimuli relative to those associated with first word stimuli. Statistically, P2 was larger for first word responses, displaying a vertex to left-hemisphere topography compared with responses to targets, which were more equipotential. The N400 was larger for responses to targets centrally, whereas responses to first word stimuli displayed a frontal topography. The only component to be elicited solely by the target was the Slow Wave, which was larger for related than unrelated responses parietally. This may indicate that related information is more easily retrieved from long-term memory than unrelated information (Rösler, Heil, & Glowalla, 1993; Uhl, Lang, Lang, Kornhuber, & Deecke, 1990).

In summary, the similarity in the components identified for both the first and second word stimuli implies that similar stages are used for the processing of both stimuli. The nature of the paradigm requires preparatory processing in anticipation of the second word, affecting the characteristics of the components in terms of topography and amplitude

8.1.2. EXPERIMENT 2

A multi-tasking design was used in Experiment 2 that enabled the comparison of processing associated with a silent-reading task and a relatedness-judgement task. The purpose of the study was to observe the extent to which a priming effect on N400 amplitude would occur in each task. This design also addressed the issue of whether the N400 and P3 priming effects are independent. In Figure 8.2 below, PCA-defined latency ranges are used to identify each component. In Experiment 2 the P2, N400 and P3 components were common to both prime and target processing. As in Experiment 1, CNV and the Slow Wave were only associated with prime and target processing, respectively.

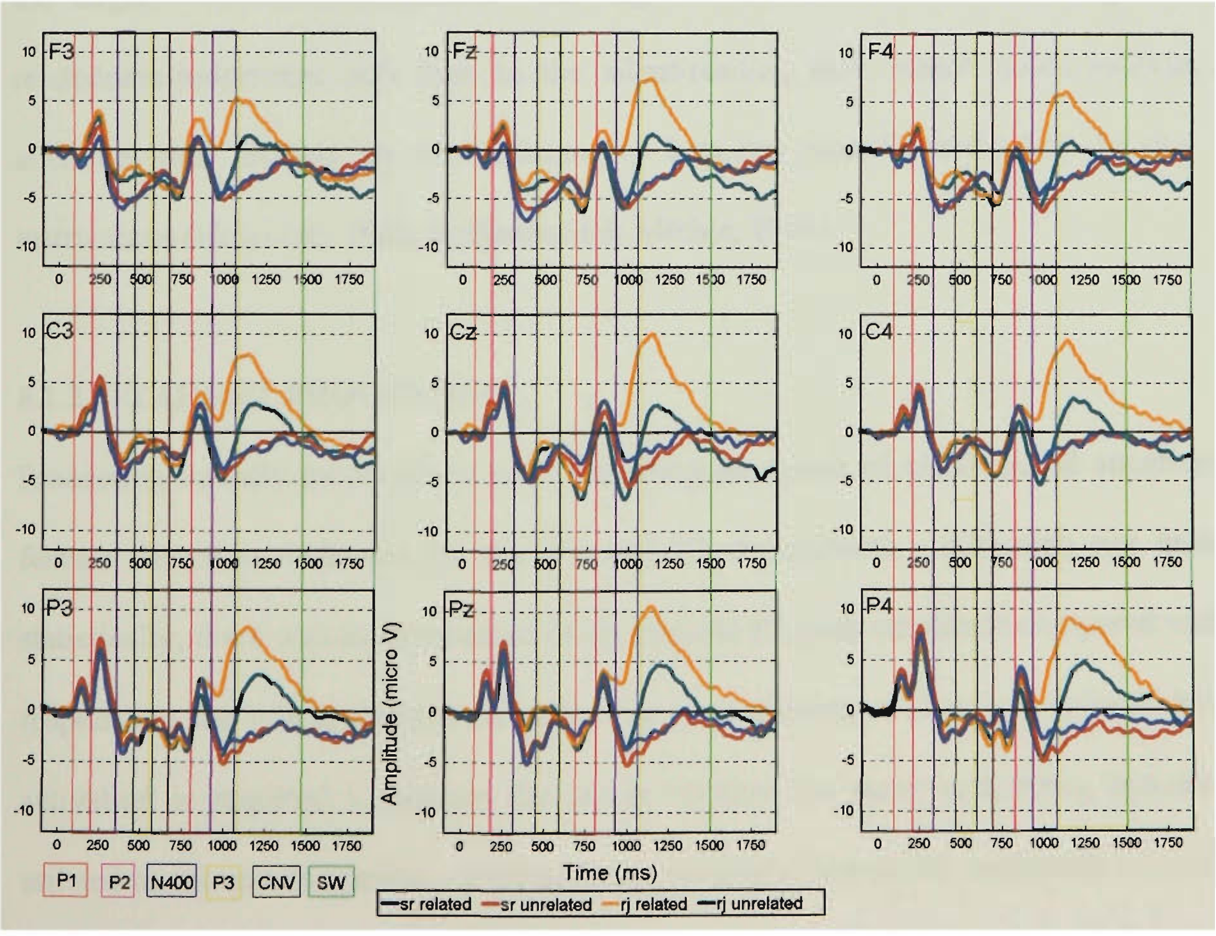


Figure 8.2. Identification of components in the grand average ERPs evoked by related and unrelated primes and targets in the silent-reading and relatedness-judgement tasks.

8.1.2.1. PRIME PROCESSING

Although P1 was not clearly distinguishable in the factors associated with the PCA, Figure 8.2 above illustrates a predominantly parietally-distributed P1 indicating early visuo-spatial attention. Early encoding processes and feature detection are indicated by the P2. This was followed by the N400, associated with lexical-semantic processes. The frontal attenuation of the N400 in the relatedness-judgement task compared with the silent-reading task may reflect the extent to which attention was directed to word identification and the activation of word meaning. P3 was only evident for the prime in the relatedness-judgement task. This indicates that subjects attended to and evaluated the prime differently between the two tasks (Bentin et al., 1985; Kellenback & Michie, 1996). CNV was the final component related to prime processing and occurred in anticipation of the target. The CNV amplitude was larger over the frontal midline region in the relatedness-judgement task than in the silent-reading task, which could indicate that attention was focused on the relationship between stimuli established by the task instructions (Holcomb, 1988; Kellenbach & Michie, 1996).

8.1.2.2. TARGET PROCESSING

Processing initially involved the early encoding processes of visuo-spatial attention and feature detection, reflected by the P1 and P2 components. Although not analysed statistically, there was an attenuation of the parietal P1 peak amplitude compared with the response to the prime, perhaps reflecting 'process priming'. That is, a reduced level of activation is required to process the target because the same underlying process was utilised to process the prime. A relatedness priming effect on P2 amplitude was evident over the midline region in the relatedness-judgement task. The priming effect on P2 amplitude for targets suggests that it may also be related to endogenous cognitive

processes, which is consistent with similar claims made by McDonough, Warren and Don (1992). However, this effect may merely reflect priming of target features as a result of activation from the prime; this will be explored further in the section relating to modelling. The P2 was followed by N400, which displayed a larger priming effect on amplitude in the relatedness-judgement task than the silent-reading task. The relatedness priming effect on N400 amplitude has been described as reflecting the ease with which a word can be integrated into the preceding attended context (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Kellenbach & Michie, 1996; Swabb, Brown, & Hagoort, 1997). The difference in the magnitude of the priming effect between the two tasks suggests this integration process occurred to a much greater extent in the relatedness-judgement task, which is consistent with the relative task demands. A robust P3 was elicited only in the relatedness-judgement task, and only responses to targets displayed a priming effect on P3 amplitude. The P3 is specific to attended items and is associated with stimulus evaluation and binary decision, characteristics consistent with the relatedness-judgement task. The Slow Wave, elicited solely by the target, has been associated with retrieval of information stored in long-term memory. A priming effect on Slow Wave amplitude was apparent only in the relatedness-judgement task. It differed from that in Experiment 1 in that the Slow Wave was larger for unrelated than related target responses over the vertex region in the relatedness-judgement task. However, this process may still reflect the ease with which related items are retrieved from long-term memory. The difference in topography and the reversal of the effect relative to Experiment 1 may be the result of component overlap with the P3 (see Figure 8.2).

In general, the components identified with target processing are similar to those associated with prime processing, implying that similar stages of processing are occurring. The

frontal attenuation of N400 amplitude elicited by primes in the relatedness-judgement task compared with the silent-reading task suggests that the underlying processes are used differently in each task. That is, word identification and the activation of word meaning may occur to a greater extent in the relatedness-judgement task than the silent-reading task. The larger CNV in the relatedness-judgement task indicated that preparatory processing occurred to a greater extent than in the silent-reading task. This in turn would be expected to affect the amplitude and distribution of the components elicited by the target.

8.1.3. EXPERIMENT 3

The PCA in Experiment 3 revealed the same factors as Experiment 2, the only difference being the order, that is, the relative extents to which the factors accounted for the variance. The components identified that were common to both prime and target processing were P2, N400 and P3. As in Experiments 1 and 2, CNV and the Slow Wave were associated with prime and target processing, respectively (see Figure 8.3).

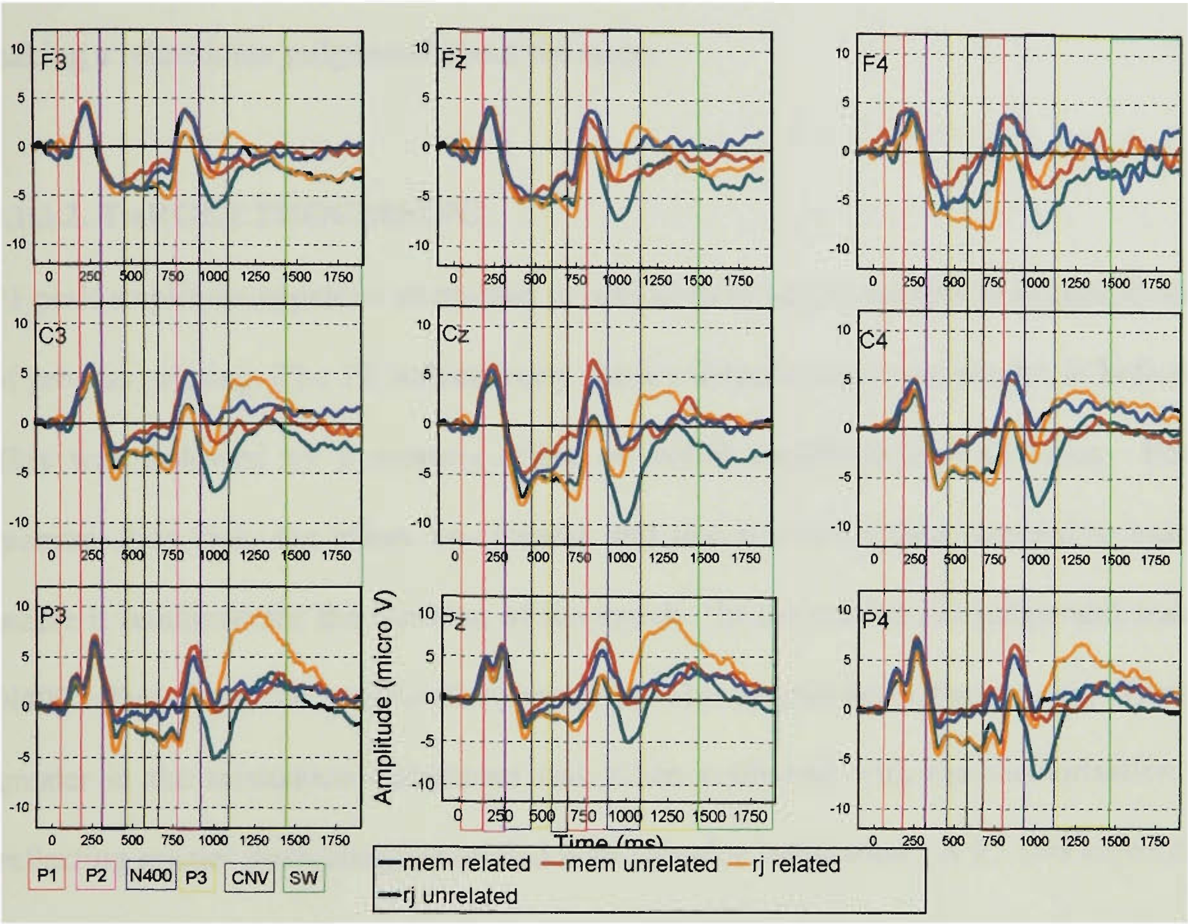


Figure 8.3. Identification of components in the grand average ERPs evoked by related and unrelated primes and targets in the memorisation and relatedness-judgement tasks.

8.1.3.1. PRIME PROCESSING

Although not identified in the PCA, processing associated with visuo-spatial attention is evident from the parietally-distributed P1 (see Figure 8.3). Early encoding associated with feature detection is indicated by the P2 component. This processing was followed by lexical-semantic processing, reflected by the presence of an N400. At this point, activation in the memorisation task appears to return to baseline until the presentation of the next stimulus. In the relatedness-judgement task, N400 was followed by P3, indicating attention to and evaluation of the prime. The CNV occurred in anticipation of the target, but only in the relatedness-judgement task. This may indicate that the words in the memorisation task were being processed as discrete units, whereas in the relatedness-

judgement task, information-processing of the prime was crucial and associated with making a relatedness judgement about the target.

8.1.3.2. TARGET PROCESSING

P1 peak amplitude appeared attenuated in responses to targets relative to primes, evidence of process priming. The P2 reflects early feature detection and was similar in both tasks. This was followed by a priming effect on N400 amplitude in both tasks. For the memorisation task, the effect was frontal, and that activation then returned to baseline, where it remained for the duration of the epoch. In the relatedness-judgement task, the N400 effect displayed a parietal topography. The magnitude of the priming effect was greater in the relatedness-judgement task when compared with the memorisation task, reflecting greater processing associated with stimulus integration. A P3 was evident only in the relatedness-judgement task, and displayed a priming effect which may reflect stimulus evaluation in preparation for the binary decision. The Slow Wave was dominant in the relatedness-judgement task, and also displayed a priming effect, but this only approached statistical significance.

As in Experiments 1 and 2, the stages of processing associated with the prime were similar to that for the target. A P3 was only elicited by primes in the relatedness-judgement task, and clear task differences in the CNV imply that very different target-preparatory processing occurred. Preparatory activation following the prime influenced the topography and amplitude of the components elicited by the target.

8.1.4. SUMMARY

8.1.4.1. PRIME PROCESSING

Prime processing in all tasks elicited a parietally-distributed P1, indicating the use of visuo-spatial attention processes. A P2 was elicited in the prime responses in all tasks, indicating early stages of encoding and feature detection. The P2 was followed by the N400 component, which indicated that processes relating to word identification and meaning had occurred. The N400 was followed by a small P3, but only in the relatedness-judgement task, indicating task-specific stimulus evaluation. The CNV was most evident in the relatedness-judgement task and the delayed letter-search task, indicating processing in anticipation of the second stimulus, which is consistent with the task demands.

8.1.4.2. TARGET PROCESSING

All tasks displayed an attenuation in P1 peak amplitude for responses to targets compared with primes. It is assumed that this attenuation reflects 'process priming', that is, once the processes were utilised for prime processing, less activation was required to invoke the same processing for the target. Early stages of encoding and feature detection were also evident in all tasks, marked by the presence of the P2 component. A priming effect on P2 amplitude was also evident in the relatedness-judgement task in Experiment 2, indicating that, even at early stages of encoding, some discrimination was made between related and unrelated targets. Word identification and meaning was reflected by the N400 in all tasks. A relatedness effect was dominant over the N400 epoch in the relatedness-judgement task and this effect has been associated with the process of semantic integration. It should be noted that the effect was not merely an attenuation of N400 amplitude in the related condition, but also an increase in amplitude in the unrelated condition relative to prime responses. This increase in amplitude may indicate that the target word was not what was

expected given the semantic context created by the prime. This was followed by a P3 component, but only in the relatedness-judgement task. The P3 indicates task-specific stimulus evaluation and the relatedness effect on P3 amplitude most likely reflects the evaluation of relatedness information in preparation for an overt response (Donchin, 1981). The Slow Wave was apparent in the delayed letter-search task and the memorisation task, and was prominent in the relatedness-judgement task. The priming effect on Slow Wave amplitude may indicate that related information is more easily retrieved from long-term memory than unrelated information.

8.2. DIFFERENCE WAVES

This section will use difference waves to explore the differential processing associated with variations in relatedness in each task in the three experiments. Difference waves were formed by subtracting the ERPs of the related from the unrelated condition to visually represent the affect of relatedness. The logic behind the use of difference waves is that if a component *X* is assumed to be constant across two experimental conditions, while an overlapping component *Y* is assumed to be variable, then the affect of *Y* can be visually represented by subtracting the ERP elicited in one condition from that of the other condition. If component *X* is truly constant across the two conditions then there will be no residual activity from this component. Any residual activity emerging from the subtraction is assumed to be associated with variations in component *Y* (Pritchard, Shappell, & Brandt, as cited in Jennings, Ackles, 1991). A limitation of this approach is that physiological processes are not usually additive, that is, physiological processes are complex and do not differ from one another in a simple manner. As a result, Picton et al. (2000) states that "the difference waveform may represent the superimposed effects of processes that were specific to both the minuend and subtrahend ERP waveforms" (p. 140). The following section is more speculative than earlier sections, in order to achieve a coherent account of the diverse findings in these experiments.

8.2.1. EXPERIMENT 1

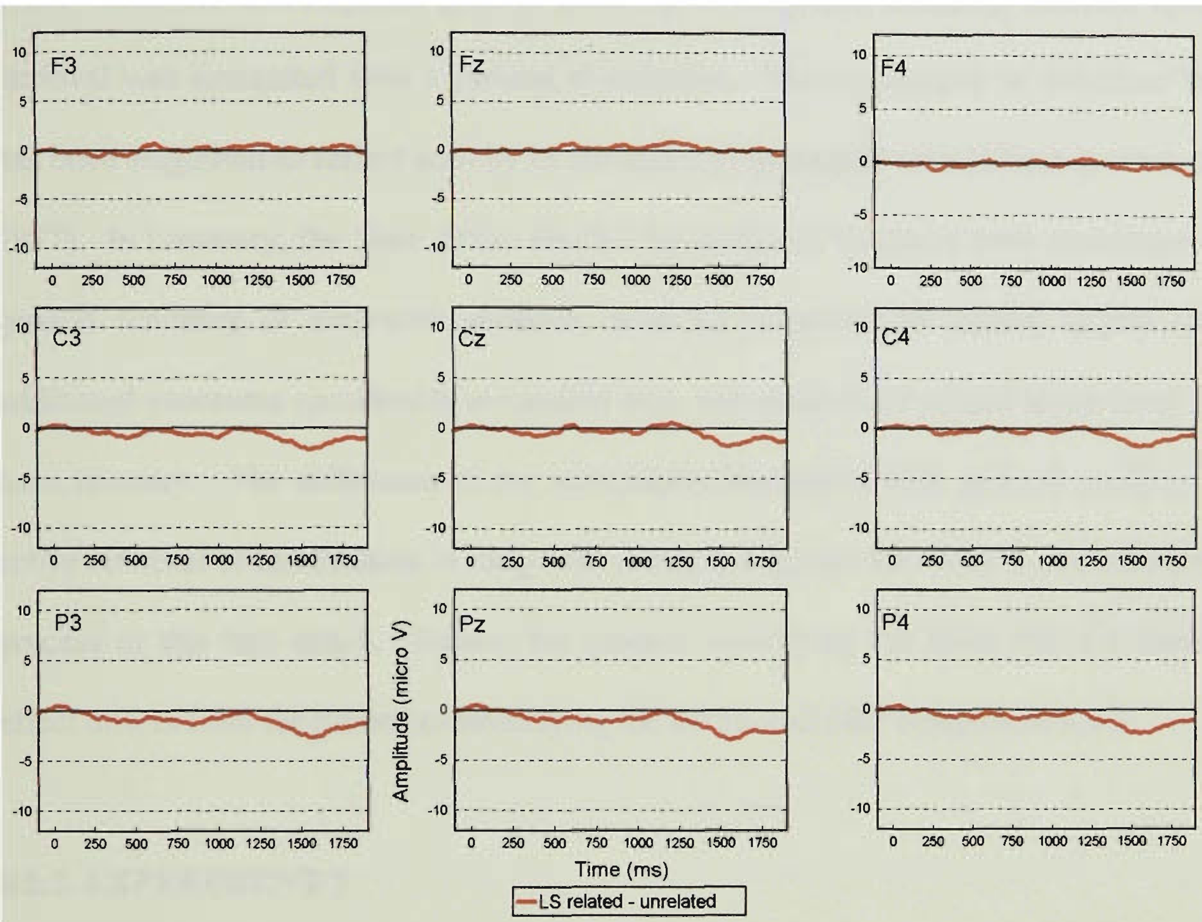


Figure 8.4. Difference wave formed for the letter-search task by subtracting the unrelated from the related condition.

The difference wave associated with Experiment 1 (see Figure 8.4) indicates that a small negative (related < unrelated) effect of relatedness emerged in the late period corresponding to the Slow Wave elicited by targets. It commenced post-N400 processing, at approximately 475 ms, peaking at about 900 ms and continuing for the duration of the epoch. Across conditions the Slow Wave displayed a fronto-central midline topography (see Figure 8.1), whereas the relatedness effect was largest parietally (see Figure 8.4 above). Rösler, Heil and Glowalla (1993) concluded that the retrieval of different contents, stored permanently in an associative network, results in distinct strategies when conclusions about these contents are required, and this is reflected in the topographic

differences over the frontal and parietal sites. They reported a frontally-distributed Slow Wave when the task required general scanning of long-term memory, whereas specific retrieval was associated with a parietal distribution. The topography of the Slow Wave has been suggested to reflect activity in the underlying cortical area (Elbert & Rockstroh, 1987). In summary, the Slow Wave elicited by unrelated targets is most consistent with general scanning of long-term memory, whereas responses to related targets reflect additional processes specifically associated with the retrieval of related items from long-term memory. The difference in the topography associated with general scanning and active retrieval of information in long-term memory suggests that there is some additional process in this late epoch. Hence, the process underlying the Slow Wave relatedness effect differs from the processes underlying the traditional ERP component itself.

8.2.2. EXPERIMENT 2

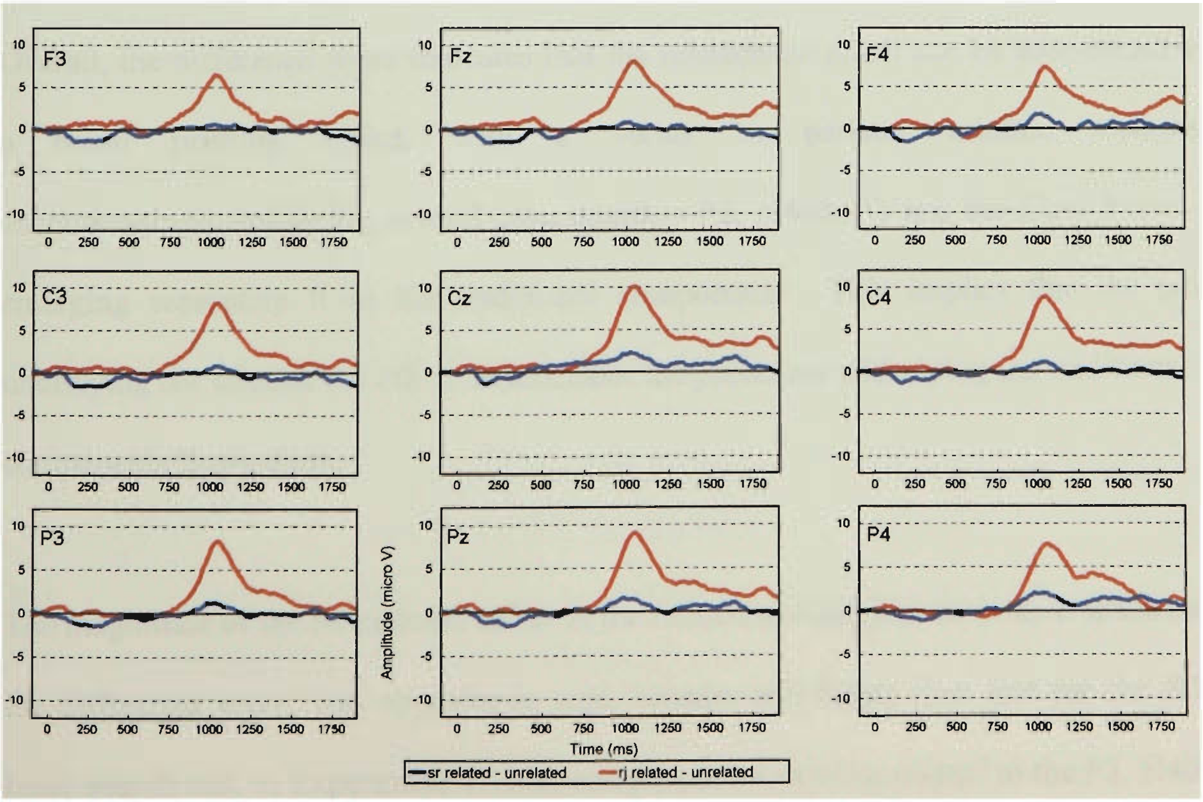


Figure 8.5. Difference waves formed for the silent-reading (sr) and relatedness-judgement (rj) tasks by subtracting the unrelated from the related condition.

The difference waves in Figure 8.5 indicate that there was little priming effect in the silent-reading task. However, the difference wave for the relatedness-judgement task displayed a distinct, broad positive priming effect (related > unrelated) commencing in the target P2 epoch, peaking in the N400 epoch, and extending through to incorporate the P3 and Slow Wave epochs. The N400 elicted by targets in the relatedness-judgement task produced a fronto-central midline to right-frontal maximum, whereas the N400 relatedness effect elicited by targets displayed a vertex maximum with a slight right bias. The interesting outcome is that the difference wave associated with the relatedness-judgement task clearly indicates that the relatedness effect peaks prior to the onset of the P3, indicating that the priming effect on N400 amplitude occurs independently of the P3 itself, but that this broad priming effect probably underlies the P3 priming effect. Figure 8.5 illustrates that at 1250 ms the relatedness effect continues through the Slow Wave epoch, displaying a vertex maximum, whereas across relatedness in the relatedness-judgement task, the Slow Wave to targets displayed a midline to frontal topography. Overall, the difference wave indicates that the relatedness effect can be conceptualised as a broad priming effect, with a vertex to parietal midline topography, encompassing/overlapping several components - P2, N400, P3 and the Slow Wave - but emerging separately from the traditional components. This implies that the process underlying the relatedness effect differs from the processes underlying the traditional ERP components themselves.

The magnitude of the relatedness effect in the relatedness-judgement task, as illustrated by the difference wave, was opposite in sign, broader and larger than that for the delayed letter-search task in Experiment 1. It encompassed processing related to the P2, N400, P3 and Slow Wave components. In Experiment 1 the effect was reversed and much smaller,

and restricted to the Slow Wave epoch. That is, in the delayed later search task the relatedness effect was specific to Slow Wave processes, compared with the broad relatedness effect obtained in the relatedness-judgement task, distinguishable from the individual ERP components. This suggests that the priming in Experiment 1 was task-specific and involved a process different from that apparent in the Experiment 2 relatedness-judgement task, while the silent-reading task did not invoke a relatedness priming effect.

8.2.3. EXPERIMENT 3

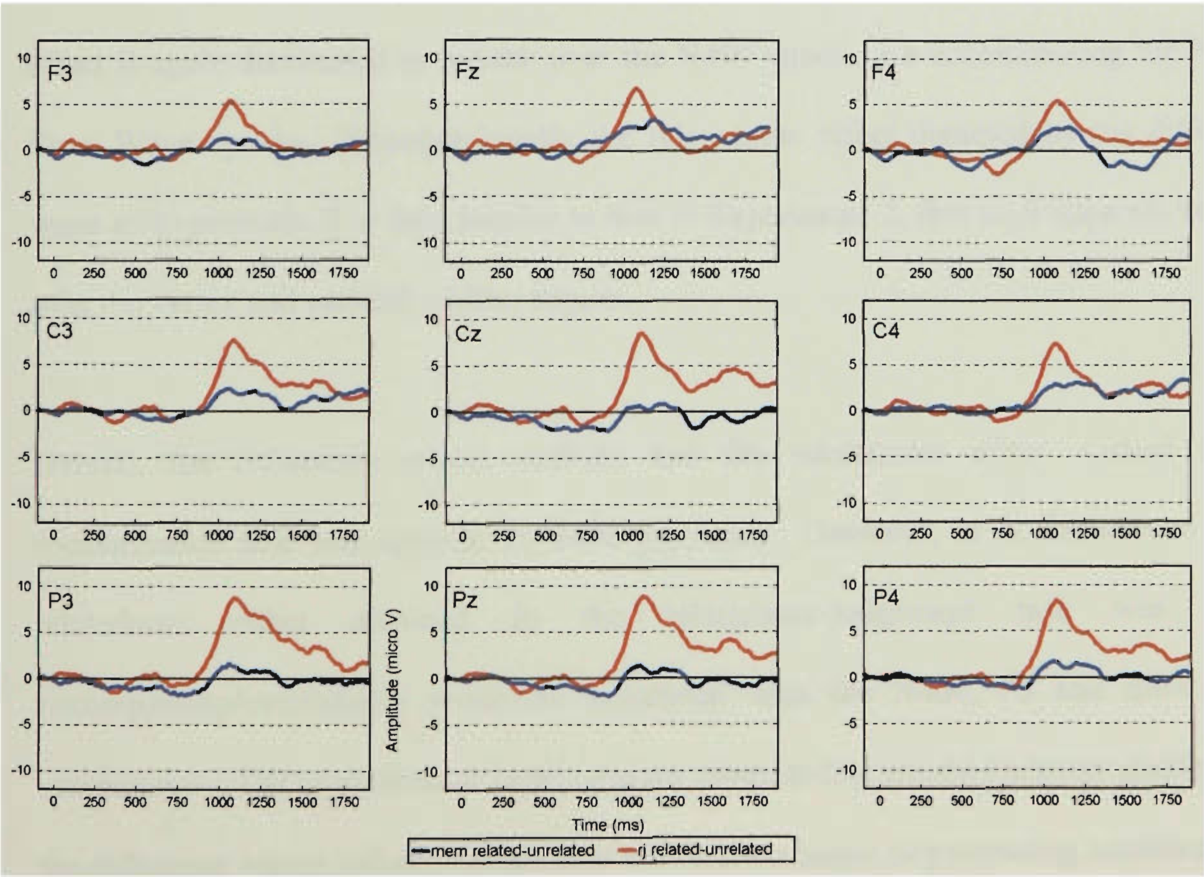


Figure 8.6. Difference waves formed for the memorisation (mem) and relatedness-judgement (rj) tasks by subtracting the unrelated from the related condition.

The positive difference wave associated with the memorisation task was small and displayed a frontal midline to right topography. Figure 8.6 indicates that the effect was

specific to the N400 epoch. Since the difference wave displayed a priming effect in the memorisation task solely over the N400 latency range, this is evidence that the priming effect on N400 amplitude may occur independently of any effects on P2, P3 or the Slow Wave.

The positive difference wave for the relatedness-judgement task displayed a distinct, broad priming effect similar to that described for Experiment 2. The main difference between the effects in the two experiments was that the effect in Experiment 3 does not encompass the P2 epoch, commencing closer to the onset of the N400 component. Also, the peak of the effect appears broader compared to that in Experiment 2. The relatedness effect is again dominated by a peak over the N400 epoch, and encompassing the P3 and Slow Wave epochs. Topographically the relatedness effect depicted by the difference wave in Experiment 3 is very similar to that in Experiment 2, that is, it appears maximal over the vertex and parietal midline region.

Overall, the difference waves indicate that the relatedness effect elicited in the memorisation task was specific to N400 processes. However, as in Experiment 2, the relatedness effect obtained in the relatedness-judgement task was broad, encompassing/overlapping processes associated with the N400, P3 and Slow Wave components. The conventional interpretation suggests that residual activity displayed by the difference waves reflects variation at the discrete stages of processing associated with each individual ERP component. However, the broad residual effect found here, with its distinct topography, can be conceptualised as a single distinct process/signature that covers a time line encompassing the traditional ERP components, differing from the original components, which are usually identified with discrete stages of processing.

8.2.4. SUMMARY OF THE DIFFERENCE WAVES

The difference wave associated with Experiment 1 indicated that there was a small negative (related < unrelated) relatedness effect, specific to the Slow Wave epoch, that displayed a parietal topography. In Experiment 2 the positive difference waves illustrated that there was no/minimal relatedness effect in the silent-reading task relative to that associated with the relatedness-judgement task, which displayed a broad relatedness effect with a vertex to parietal midline topography, encompassing/overlapping the P2, N400, P3 and Slow Wave components. It was interesting to note that the relatedness effect on the Slow Wave amplitude was reversed in Experiment 2 relative to that in Experiment 1. This may reflect task-specific processing associated with Experiment 1, in which prime-target relatedness was peripheral to the task. The broad relatedness effect in Experiment 2 was also evident in the relatedness-judgement task used in Experiment 3, displaying a similar vertex and parietal midline topography. However, in Experiment 2 the broad relatedness effect commenced at the onset of the P2 component whereas the onset was delayed in Experiment 3, commencing at the onset of the N400 component. The memorisation task also displayed a relatedness effect, but it was smaller and specific to the N400 epoch, displaying a frontal midline to right topography.

The difference waves associated with the relatedness-judgement tasks displayed a broad residual effect, with a distinct topography. The conceptualisation of a single distinct process/signature encompassing the traditional ERP components may be at odds with the distinct processes associated with the components described in Section 8.1. It could be that the distinct signature formed by the difference wave in the relatedness-judgement tasks represents a dependent flow of activation between processing stages in order to meet task demands, in this case, explicitly determining the relatedness between prime and

target.

8.3. DESIGN TECHNIQUES

Design techniques unique to each experiment were also used to investigate the processing nature of the N400 component and component overlap of the N400 and P3. The letter-search task, silent-reading task and memorisation task used in Experiments 1, 2, and 3, respectively, are design techniques used to eliminate the confounding problem of N400/P3 overlap and enabled the mechanisms of semantic priming and the organisation of semantic memory to be studied without explicitly drawing the subject's attention to the semantic processes that were being investigated. The silent-reading task, and the memorisation task, used in Experiments 2 and 3 respectively, was compared with a relatedness-judgement task, which explicitly required subjects to utilise semantic processes. The findings of the different experimental techniques will be discussed in turn, specifically in relation to N400 processing and component overlap.

8.3.1. EXPERIMENT 1

The aim of the first experiment was to replicate the delayed letter-search paradigm used by Kutas and Hillyard (1989). They reported that the relationship between the prime and target modulated the response to the target in relation to N400 amplitude, even though the semantic relationship between the word pairs was completely irrelevant to the task. They tentatively concluded that the N400 reflected an automatic component of semantic priming. Although the letter-search task used in Experiment 1 is considered to only require a shallow processing of letter strings, the behavioural data showed that letter-search performance was better when the words were related than when they were unrelated, regardless of letter presence. This implies that the task was not performed by

merely matching the visual features of the target letter with the letter strings of the first and second stimulus presented in each trial. The ERP amplitude differences in the Slow Wave elicited by related and unrelated target responses, and the behavioural difference described above, suggests that linguistic information was accessed and influenced task performance. In addition, principal components analysis extracted a distinct N400 factor. Even though this indicates that linguistic information was accessed and an N400 was elicited, the priming effect on N400 amplitude reported by Kutas and Hillyard (1989) was unable to be replicated in Experiment 1. An interesting outcome was that primes elicited a larger N400 than targets, and that will be interpreted later in this section.

Adapting the interpretation put forward to account for the data of Brown and Hagoort (1993), it can be argued that the nature of the processing associated with the letter-search task prevented the conscious awareness of the word meanings, preventing the words from being integrated into a higher-order representation of the context in which they were presented. So why was there an N400 present at all, and why was it larger for the first word in the pair ('prime') than that elicited by the second word ('target')? Deacon, Mehta, Tinsley and Nousak (1995) suggested that the "N400 reflects a process, such as the activation of orthographic codes, or the attempt to access semantic representations, which may precipitate, but is not itself a manifestation of, the conscious awareness of word meanings" (p. 561). Also, Holcomb (1988) suggested that N400 is sensitive to both automatic and controlled priming mechanisms. This implies that the N400 is a unitary process that can be activated by multiple input processes. These studies imply that the mere presence of the N400 component reflects an automatic process. The smaller N400 to targets compared with primes may indicate that a reduced level of activation was required to process the target because the same underlying process was utilised to process

the prime.

The N400s to primes and targets visually appear to be much larger in the relatedness-judgement task used in Experiment 2 and 3 (Figure 8.2 and 8.3) than those elicited by the first and second word stimuli in the letter-search task used in Experiment 1 (Figure 8.1). This may imply less activation of orthographic codes or semantic representations in Experiment 1. Such processing might have been inconsistent with optimal performance in the letter-search task. A priming effect on N400 amplitude may not have occurred because the word-pairs were processed without the explicit need to access or integrate semantic information into a context.

8.3.2. EXPERIMENT 2

The silent-reading task used in Experiment 2 failed to elicit a distinct priming effect on the amplitude of any ERP component and there was no behavioural data associated with the task to determine if any form of priming had occurred. A distinct N400 factor was identified in this task using principal components analysis, and a minimal priming effect on N400 amplitude was obtained. This finding is in contrast to Chwilla, Brown and Hagoort (1991), who reported a distinct priming effect on N400 amplitude in a similar task. The main difference was that they manipulated the proportion of related word pairs in the stimulus lists presented to form a high (80%) or low (20%) proportion condition. The priming effect on N400 amplitude was larger in the high proportion condition. It was suggested that the larger priming effect on N400 amplitude in the high proportion condition could reflect the use of expectancy strategies. That is, where a target is preceded by a prime word, an expectancy set is generated based on the prime word and is comprised of words that are related to the prime. Target recognition may have been

facilitated using the expectancy strategy in the high proportion condition because the expected word would have been consistent with the perceived word at a greater than chance level. However, an equal proportion of related and unrelated word pairs were used in Experiment 2, and such task conditions are unlikely to involve the use of an expectancy strategy to the same extent. The words in the silent-reading task may have been processed more individually, as task demands did not require the active integration of the prime and target in order to make any type of decision. The larger priming effect on N400 amplitude in tasks that benefit from the integration of the prime and target is evident in the relatedness-judgment task used in Experiment 2. In the relatedness-judgment task, prime processing may generate expectancy for a set of words, and the integration process uses the semantic context to determine if the expected word is consistent with the word presented as the target. This proposal is consistent with Brown and Hagoort's (1993) failure to find an ERP effect of masked semantic priming, despite behavioural evidence for masked semantic priming. It is assumed that masking prevented the integration process from occurring. However, their study did not carefully titrate prime durations to confirm that subjects were tested at their masking thresholds. It may well be that Brown and Hagoort's participants were below the threshold necessary for ERP masked priming. In fact, Deacon et al. (2000) set the individual masking thresholds for each subject in advance and obtained masked semantic priming effects on the N400 component. However, if the priming effect obtained on N400 amplitude under masked conditions reflects a purely automatic process, then a distinct priming effect on N400 amplitude should have occurred in the silent-reading task used in Experiment 2.

8.3.3. EXPERIMENT 3

The memorisation task displayed a behavioural priming effect. The mean percentage of correctly-recognised word pairs that were previously presented was greater for related than unrelated word pairs, indicating that semantic information was utilised to perform this task. A small priming effect on N400 amplitude did occur in this task, but no other ERP priming effects were significant. The presence of a priming effect on N400 amplitude in the absence of the P3 component clearly indicates that the priming effect on N400 amplitude can occur completely independently of the P3 component.

Behaviourally, responses to related targets were significantly faster than those to unrelated targets in the relatedness-judgement task. A robust priming effect on N400 amplitude was obtained. The larger priming effect on N400 amplitude in the relatedness-judgement task relative to that associated with the memorisation task supports previous work which has concluded that the priming effect on N400 amplitude elicited by the target is not enhanced in tasks which do not encourage the analysis of the semantic context (Bentin, Kutas, & Hillyard, 1993; Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Chwilla, Hagoort, & Brown, 1998; Kellenbach & Michie, 1996). The larger priming effect on N400 amplitude in the relatedness-judgment task compared with the memorisation task suggests that that the N400 is more sensitive to controlled priming mechanisms. If the N400 amplitude was sensitive only to automatic/implicit priming mechanisms, such a vast difference in the magnitude of the N400 priming effect between tasks would not be expected.

So far, it can be speculated that the N400 may represent the automatic activation of semantic attributes associated with a word, which provides a semantic context and enables

the generation of an expected set of words in anticipation of target presentation. However, the use of the integration process depends on the extent to which the semantic context plays a role in performing the task. In this sense the integration process represents the controlled aspect of processing. That is, the contextual information generated by the prime may not require a higher-level interpretation of the discourse in order to perform the task. If this interpretation is applied to the current experiments, it could be suggested that contextual semantic analysis, reflected by the priming effect on N400 amplitude, was greatest in the relatedness-judgment task, followed by the memorization task, then the silent-reading task, and absent in the letter-search task

However, as mentioned previously, Deacon, Hewitt, Yang and Nagata (2000) replicated a masked priming study by Brown and Hagoort (1993) using a shorter stimulus onset asynchrony. Contrary to Brown and Hagoort (1993), a priming effect on N400 amplitude was obtained for masked and unmasked words. It was concluded that the processing subserving the N400 was pre-lexical because the subjects were not able to identify the words. Also, Rolke, Heil, Streb and Hennighausen (2001) used a variation of an attentional blink task in which three target words had to be identified among distractors in a rapid serial visual presentation task. The second word acted as the prime and the third the probe, and the strength of the association between the second and third words was varied. They reported that the identification of prime words was impaired. The primes that failed to be identified did not elicit a P3, which was taken to indicate that the prime words were not explicitly recognised. It was concluded that automatic spreading activation was evoked by the missed primes and this was sufficient to invoke an N400 effect. That is, missed primes activated semantically-associated words and related target words formed part of this set; as a result of this the recognition of the target word was

facilitated, and reflected by the N400 effect.

The nature of both of the tasks mentioned in the previous paragraph may not have allowed sufficient time for strategic attentional processing to occur. It was therefore concluded that the priming mechanism of automatic spreading activation was sufficient to invoke an N400 effect. It can be speculated that the automatic process of spreading activation is, or is part of, the attentional process of contextual semantic integration and reflects processing given insufficient time for much strategic, higher-order cognitive processing to occur. When sufficient time is allocated, activation of the semantic integration process becomes task dependent. That is, the priming effect on N400 amplitude reflects the automatic process of semantic integration which, given experimental circumstances, can be strategically controlled. However, this interpretation does not adhere strictly to the inflexibility which commonly defines an automatic process (Neely, 1977; Posner & Snyder, as cited in Solso, 1975; Shiffrin & Schneider, 1977). Such inflexibility differs from the Holcomb (1988) interpretation of the N400, which assumed that it is sensitive to both automatic/implicit as well as more overt controlled priming mechanisms. The current interpretation suggests that the N400 reflects a unitary but automatic priming mechanism that can be controlled. In terms of priming mechanisms, spreading activation occurs automatically, providing an expectancy set in relation to the context, but given sufficient time the extent of this processing is controlled and task-dependent effects emerge as a result.

8.4. OVERLAPPING COMPONENTS

Overlap between the N400 and P3 in previous research has made it difficult to determine whether the N400 effect is due to variation in N400 amplitude alone, or whether it

emerges as an artefact of component overlap with a P3 effect (Boddy, 1986; Chwilla, Hagoort, & Brown, 1998). The P3 is generally elicited as a result of a binary decision (Bentin et al., 1985; Boddy, 1986) or more generally, in tasks that require explicit identification (Rolke, Heil, Streb, & Hennighausen, 2001). The following section will review what was revealed about the component overlap between the N400 and P3 components using the techniques of principle components analysis, difference waveforms, experimental design and observation of topography. Topographically it was assumed that, if an effect of relatedness in one component is due solely to differential activity in another component, it should have the same topography. Hence, for the relatedness-judgement tasks, the topographic similarities and differences between the priming effects on target N400 and P3 amplitudes were assessed.

In terms of experimental design, apart from not drawing the subject's attention to the semantic processes under investigation, the delayed letter-search task, the silent-reading task and the memorisation task did not require the immediate overt response commonly associated with the P3. This avoided any overlap between N400 and the decision-related/identification processing underlying the P3 response. A relatedness-judgement task was also used in the second and third experiments to provide a comparison between tasks that did and did not elicit a P3.

In Experiment 1 a factor consistent with the N400 was identified in the absence of a factor consistent with the P3 component, indicating that the delayed letter-search task was successful in eliminating the P3. However, statistically there was no priming effect on N400 amplitude. The difference wave also failed to show any residual effect over the N400 latency range. These results could not rule out that any priming effect on N400 may

be dependent on, or result from changes in, the P3.

A factor consistent with the N400 was obtained in the silent-reading task used in Experiment 2. A factor consistent with the P3 component was also obtained, but subsequent analysis showed that it emerged only in the relatedness-judgement task. It should be noted that the PCA indicates that the N400 and P3 are statistically-independent components. However, one of the assumptions of using PCA to analyse ERP data is that the components comprising the event-related potential are orthogonal, making the argument somewhat circular (Pritchard, Chappell, & Brandt, as cited in Jennings, Ackles, & Coles, 1991). The difference wave associated with the silent-reading task displayed a very small residual priming effect over the N400 latency range. In contrast, the difference wave for the relatedness-judgement task displayed a large broad residual effect peaking over the N400 latency range. Topographically, the N400 effect for targets in the relatedness-judgement task displayed a vertex maximum with a slight right-central bias, whereas the P3 effect displayed a central topography. Whilst the topography of the relatedness effect is quite distinct in these components, they still overlap somewhat. The evidence derived from Experiment 2 was not sufficient to imply that the priming effect on N400 amplitude occurred totally independently of the priming effect on P3.

The PCA associated with Experiment 3 revealed a factor consistent with the N400 in both the memorisation and relatedness-judgement task. A factor consistent with the P3 component was also obtained, but it was shown to occur solely in the relatedness-judgment task. The difference waves displayed a residual priming effect over the N400 latency range in the memorisation task but the effect was dominant and broader in the relatedness-judgement task. In terms of topography, the N400 effect displayed a parietal

distribution, whereas the P3 effect was evenly distributed over the entire scalp. The memorisation task elicited a small frontal priming effect on N400 amplitude in the absence of a P3 component. The relatedness-judgement tasks of Experiments 2 and 3 were the same, with the only differences being that more trials were used to form the mean ERPs in Experiment 2 than in Experiment 3, and the tasks were counterbalanced in Experiment 3. Such experimental differences may account for the shifts in the topography of the N400 and P3 relatedness effects between these experiments.

Given that the N400 effect did occur in the memorisation task in the absence of the P3 component and that there was disparity in the topography of N400 and P3 effects in the relatedness-judgement task, it is reasonable to conclude that the N400 and P3 relatedness effects can occur independently. Other studies have reported similar findings (Bentin, McCarthy & Wood, 1985; Fischler et al., 1983). The difference in the topography of the N400 effect generated in the memorisation task compared with the relatedness-judgement task may not reflect differences in the cognitive operations themselves, but the cognitive operations may have been applied to task-specific information (Doyle, Rugg, & Wells, 1996).

8.5. SUMMARY

This chapter summarised the findings of each experiment based on the information obtained from the principal components analyses and design techniques. Difference waveforms were also interpreted to further clarify the priming effects obtained.

The PCA clearly showed that the processing associated with target words was similar to that for prime words. The difference waveforms clarified that a priming effect only

occurred over the Slow Wave latency range in the letter-search task. There was no residual effect in the silent-reading task, whereas the relatedness-judgement task displayed a broad residual effect that encompassed several components (P2, N400, P3, Slow Wave). It was hypothesised that the distinct signature formed by the difference wave in the relatedness-judgement tasks may represent a dependency in the flow of activation between processing stages based on task demands. The memorisation task also displayed a residual effect, which was confined to the N400 latency range. The differences in the priming effects between tasks clearly showed that such effects are task dependent. Also, task manipulation and close assessment of topography indicated that the priming effect on N400 and P3 can occur independently.

The data and design techniques described above revealed distinct differences in the flow of activation in each experimental condition. The following chapter will attempt to model the flow of activation in each experimental condition to further assess the overall processing reflected in the event-related potential.

CHAPTER 9

MODELLING THE FINDINGS

This chapter attempts to model the flow of activation in each experimental condition within the Stoltz and Besner (1996) modified version of the Interactive Activation framework originally proposed by McClelland (1989). The Stoltz and Besner (1996) interpretation of how the model accounts for word recognition and semantic priming shall be briefly described again.

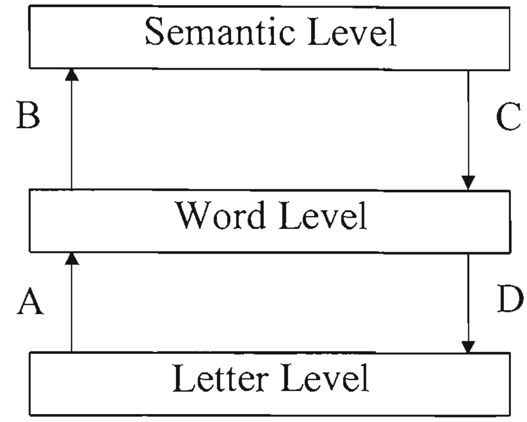


Figure 9.1. Pathways A and B provide bottom-up information whilst pathways C and D provide top-down support for the bottom-up activation. The activation between levels is excitatory whilst activation within levels is competitive, that is, stronger candidates inhibit the activation of weaker candidates (from Stolz & Besner, 1996, p. 1168).

Presentation of a word stimulus results in the activation of corresponding letter-level representations. As shown in Figure 9.1, activation then flows bottom-up via Pathway A, activating representations at the word-level (words) that include the activated letters. Through excitatory and inhibitory mechanisms, within-level competition ensures that the most appropriate word-level representation is the most active. Concurrently, word-level activation proceeds via Pathway B, activating consistent representations at the semantic level, and also associates of the activated word. Within-level competition (excitatory and

inhibitory mechanisms) ensures that the most-consistent semantic-level representation is most active. Activation along Pathways A and B reflect bottom-up processing from lower to higher levels. Activation also proceeds top-down via Pathways C and D. Activation from higher to lower levels provides top-down support for bottom-up activation. Pathway C enables activation to flow from the semantic level to the word level. This includes semantic associates activated at the semantic level. Within-level competition and bottom-up support continually fed upward from Pathway A ensures greatest activation for the presented word. Pathway D joins the word level to the letter level; bottom-up support and within-level competition ensures that activation is strongest for the letters that were actually presented.

The following section will attempt to integrate the ERP findings of the thesis with the model described above. It is commonly assumed in the literature that the stages of processing are marked by the ERP component peaks. However, it should be noted that the peaks could simply indicate the order of the processing rather than the time-locked temporal organisation of processing, although this is assumed here as a first approximation. Figure 9.2 below illustrates the timing of the ERP components identified in the delayed letter-search task and suggests the extent to which activation flows between the various levels of the model.

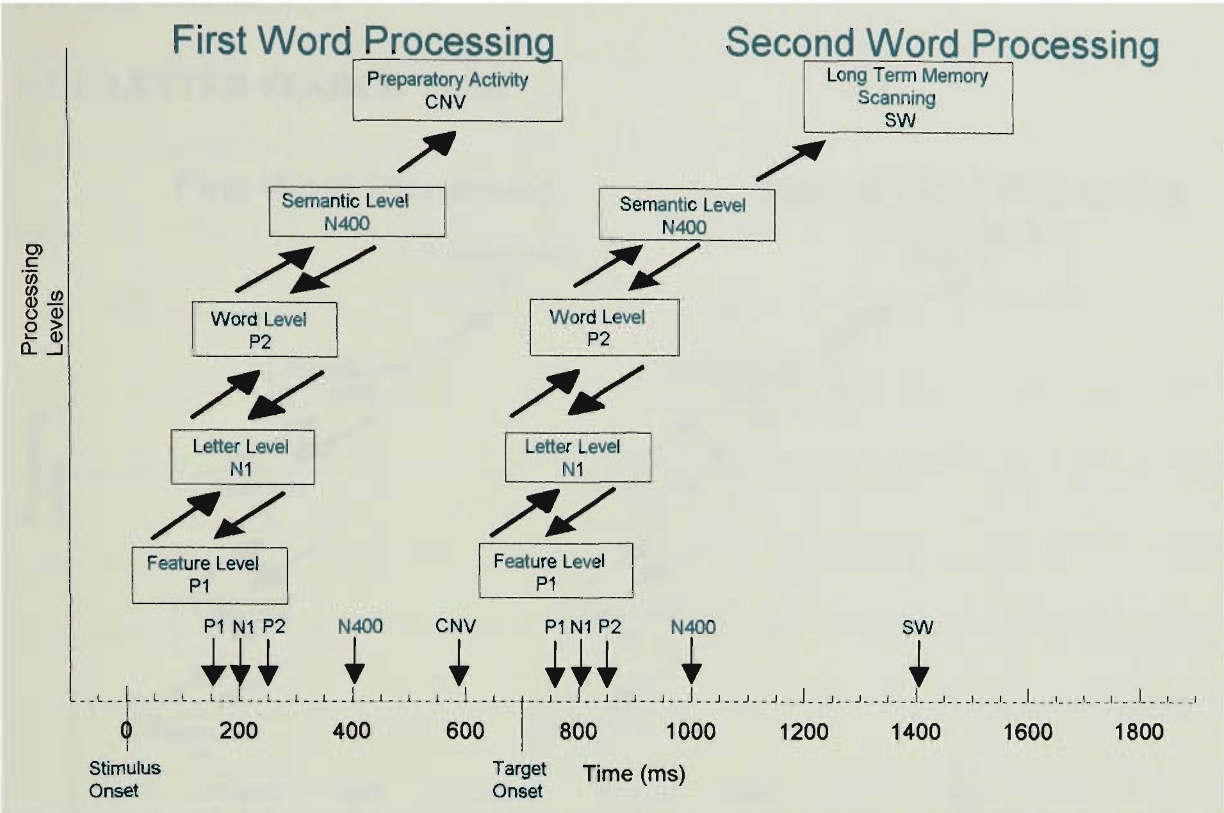


Figure 9.2. ERP processing interpreted in the interactive activation model. Arrow thickness linking levels in the following models will be used to indicate the depth of processing.

It is assumed that the rise and fall of each ERP component indicates the rise and fall of activation within a particular level of processing in the interactive activation model. The rising section of the ERP components may represent the gradual increase in within-level activation, resulting from the bottom-up and top-down activation between levels. The peak latency marks the point at which activation is maximal; activation then decays. Activation can be continually fed forward and backward until the peak latency is reached.

The following section will use the assumptions mentioned to describe prime and target processing respectively, as illustrated in Figure 9.2 above.

9.1. EXPERIMENT 1

9.1.1. LETTER-SEARCH TASK

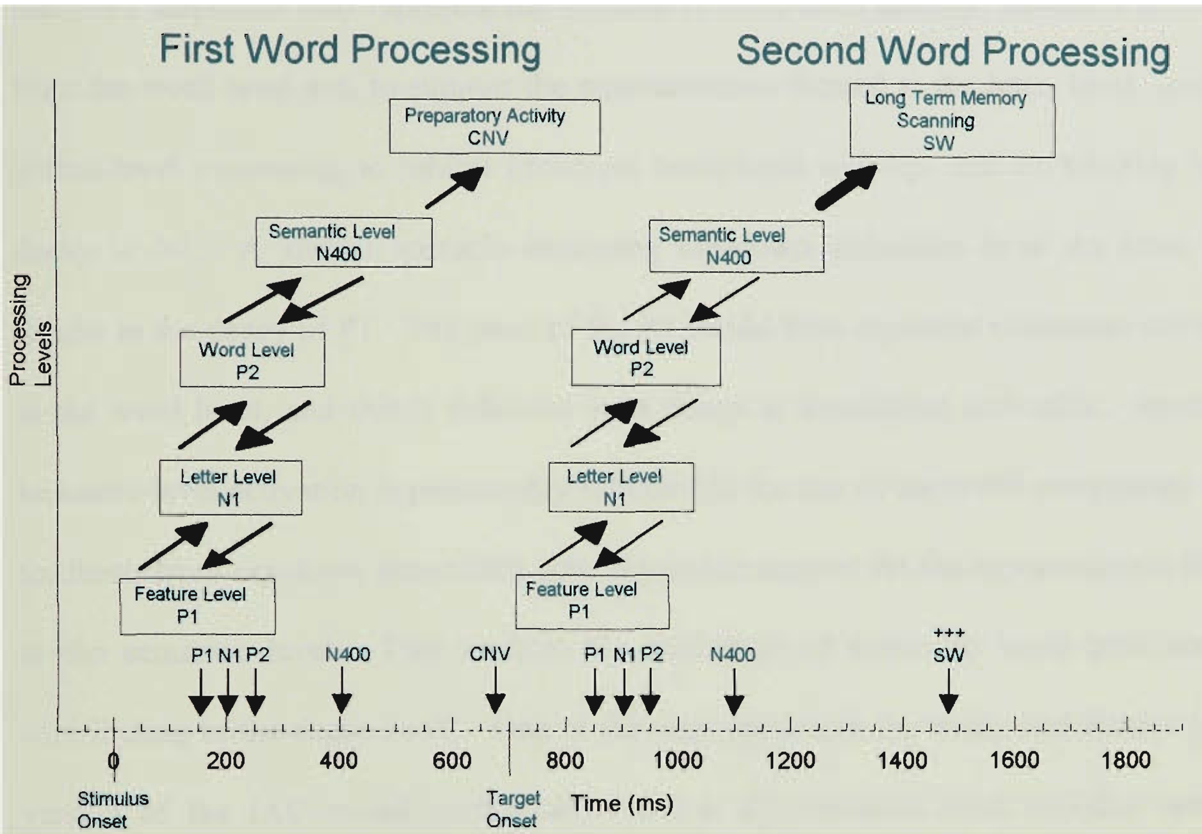


Figure 9.3. ERP processing interpreted in a modified version of the IAC model for the letter-search task used in Experiment 1. Thinner arrows associated with "target" processing indicate that less activation was required to establish recognition. The thicker arrow related to Slow Wave processing indicates a greater depth of processing at this level. The '+++' sign marks the peak of the difference wave illustrated in Figure 8.1

9.1.1.1. FIRST-WORD PROCESSING

The P1 may represent spatial attention required to gather visual feature information in order to form a representation of the letters at the letter-level. The development of the P1N1 complex may represent the gathering of information at the feature level (P1) and letter level (N1) respectively, through bottom-up and top-down processing. Whilst the peaks may reflect maximum activation of processes involved in representing the set of features and letters presented, their passing may be taken to indicate how activation at the

feature and letter levels then decays as a result of feedback from top-down processing, enabling inhibition of irrelevant letter-level activity through within-level processing. The rise in P2 amplitude may represent the increase in word level activity; top-down activation from the word level acts to support the representation formed at the letter level, enabling within-level processing to inhibit irrelevant letter-level activity, and contributing to the decay in N1. A similar scenario involving top-down activation from the letter level results in the decay of P1. The peak of the P2 would then represent maximum activation at the word level, and this is followed by a decay in word-level activation. Increasing semantic-level activation is presumably reflected in the rise of the N400 component, while feedback from top-down processing acts to provide support for the representation formed at the semantic level. This enables the inhibition of irrelevant word-level activity, contributing to the decay in P2. One of the assumptions in the Stoltz and Besner (1996) version of the IAC model is that activation at the semantic level includes semantic associates, and it is assumed that this occurred in an automatic manner. Given the nature of the task, subjects in Experiment 1 may have adopted a 'set' which focused attention at the letter and word levels, reducing the extent to which semantic associates were activated. The N400 was followed by the CNV, which reflects preparatory processing/arousal processes in anticipation of the target, possibly guided by the processing underlying the N400.

9.1.1.2. SECOND-WORD PROCESSING

Processing associated with the second word stimuli commenced in a manner similar to that for the fist word stimuli, the noticeable difference being a reduction in P1N1 and P2 amplitude. The attenuation in peak amplitude for P1N1 and P2 elicited by the second word may indicate that a reduced level of activation was required to form a representation

at the feature (P1), letter (N1) and word levels (P2), respectively (indicated by thinner arrows in Figure 9.3). This was referred to earlier as 'process priming', that is, a reduced level of activation was required to process the second word because the same underlying process, as indicated by the PCA, was utilised to process the first word. In conjunction with this, the development of P1N1 may represent the gathering of information at the feature level and letter level respectively, as it did for the processing of the first word. The model assumes that within-level competition does not result in competitive items being returned to a base-line level. For example, letters may have features in common, and activation may occur for these common features. As information is being gathered at the letter level, top-down processing may inhibit irrelevant features at the feature level. However, the irrelevant feature(s) remain partially activated because the inhibition does not result in the irrelevant feature(s) returning to a base-line level of activation. The attenuation in P1N1 amplitude may represent a reduction in bottom-up and top-down processing resulting from preactivation by the first word, which may have shared features in common with the second word. The peak is assumed to represent maximum activation of processes involved in representing the set of features (P1) and letters (N1) presented; activation then decays as a result of feedback from top-down processing. This enables inhibition, through within-level processes, of irrelevant letter-level and feature-level activity, respectively. Similarly, attenuation of P2 amplitude may indicate that a reduced level of activation was required to establish a representation of the word because the second word may have had letters in common with or similar to that of the first word.

There was a decrease in N400 amplitude for second word responses relative to that associated with prime responses. This may be taken to indicate that processing develops in the same way as for the N400 associated with prime processing, and information is fed bottom-up from the word level and top-down to the word level, gradually increasing

within-level activity at the semantic level. The decrease in peak amplitude for second word responses could indicate that lower between-level activity was required to activate word meaning and semantic associates at the semantic-level. This may indicate process priming, as described earlier. Top-down processing would have activated the second word representation and the associates at the word level, providing greatest support for the item presented and enabling inhibition of irrelevant word-level activity without driving the associates to a baseline level.

If this was the case, then why was there no priming effect on N400 amplitude? That is, why was there no attenuation in N400 amplitude elicited by related second word stimuli? Recognition of related second word stimuli should have benefited from the activation of first word associates. It is hypothesised here that, as mentioned previously, the 'set' adopted by the subjects may have focused attention predominantly at the letter and word levels, reducing the extent to which semantic associates were activated by the first word. It can be speculated that this is reflected in the smaller N400 elicited in the letter-search task relative to that associated with all other tasks in the remaining experiments. Task instructions did not indicate that there was any type of relationship between the first and second word, making it less likely that subjects would generate or focus on an expected set of words from the onset of the task. As a result, any expectancy set generated by the first word may have resulted in low activation of associated words. If words that are associated with the prime decay quickly as a result of low activation then recognition of the second word is less likely to be facilitated.

The Slow Wave amplitude was larger for related than unrelated second word stimuli. This may indicate that the scanning of long-term memory resulted in greater retrieval of

information, illustrated by the thicker arrows in Figure 9.3. That is, relatedness may have assisted retrieval of the first word in the letter-search task in order for both words to be held in anticipation of the letter probe. The residual effect of relatedness illustrated by the difference wave showed a distinct priming effect in Slow Wave amplitude, and this is indicated by the plus signs above the Slow Wave component in Figure 9.3.

9.2. EXPERIMENT 2

9.2.1. SILENT READING

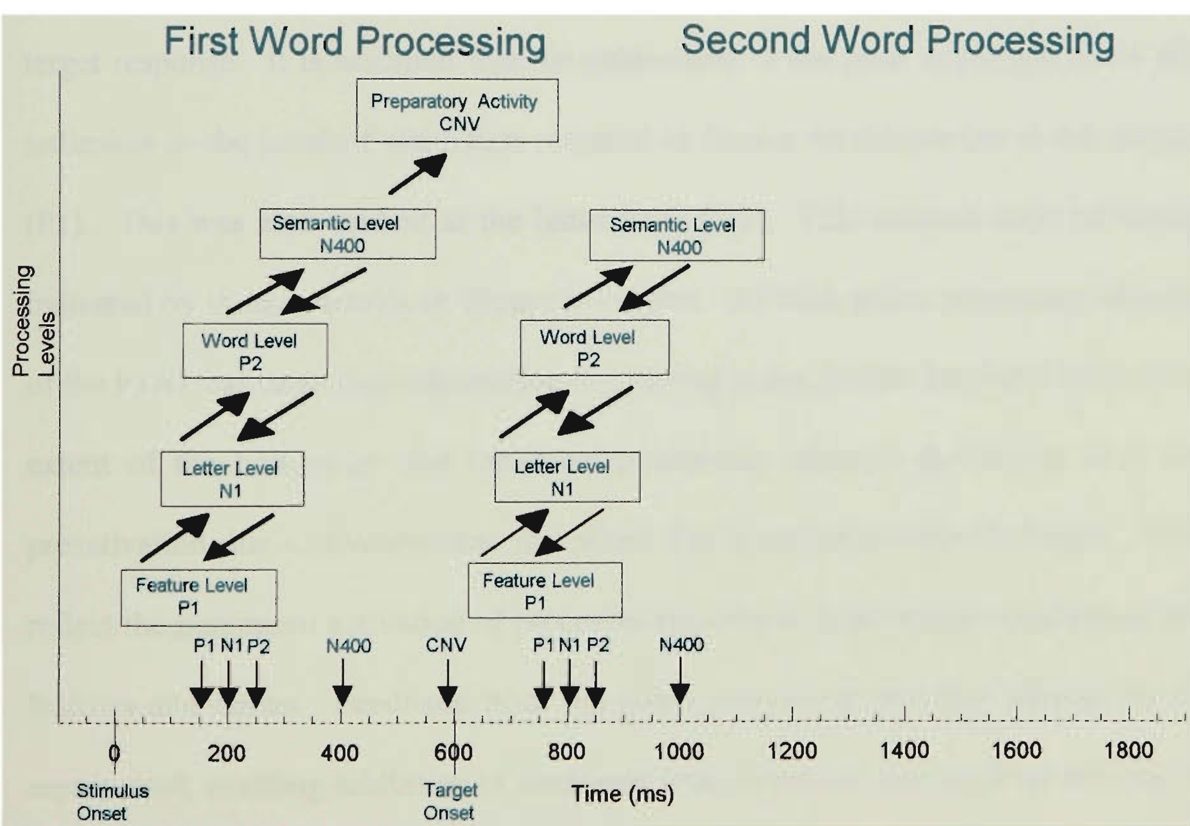


Figure 9.4. ERP processing interpreted in a modified version of the interactive activation model for the silent-reading task used in Experiment 2. Where there is thought to be minimal bias in the flow of activation for this task the same black arrow is used for the processing of the first and second word and between levels. Thinner arrows indicate a reduced level of activation.

9.2.1.1. FIRST-WORD PROCESSING

The processing of the first word was closely similar to that in the letter-search task. The N400 was again elicited by the first word. This could be taken to indicate that semantic-level activation is automatic. Activation at the semantic level may result in the automatic spreading of activation to semantically-related words. It is assumed that there are minimal attentional effects biasing the flow of activation. This was indicated in Figure 9.4 by using the same arrow size throughout the processing of the first word.

9.2.1.2. SECOND-WORD PROCESSING

As in the letter-search task, there was evidence of an attenuation in P1 amplitude in the target response. It is assumed that the attenuation in the peak amplitude of P1 reflects a reduction in the level of activation required to form a representation at the feature level (P1). This was also evident at the letter level (N1). This reduced level of activation is indicated by thinner arrows in Figure 9.4 above. As with prime processing, development of the P1N1 indicates that information is gathered at the feature level and letter level. The extent of the bottom-up and top-down processing required is reduced as a result of preactivation due to features that the prime has in common with the target. The peaks reflect the maximum activation of processes required to form a representation of the set of features and letters. Feedback from top-down processing provides support for the item represented, enabling inhibition of irrelevant letter-level and feature-level activity, through their respective within-level processing, resulting in the decay of activation. Unlike in the letter-search task, P2 amplitude was not attenuated, indicating that word recognition occurred in a similar fashion to the first word, indicated in Figure 9.4 by the use of the same type of arrow leading to and from the word-level. The lack of attenuation in P2 processing supports the argument that attention was directed to the word level in the

letter-search task, reflecting task-dependent processing

The N400 amplitude elicited by targets was similar to that for primes. Processing developed, peaked and decayed in the same way as the N400 associated with prime processing, indicated by the use of the same type of arrow leading to the semantic level in Figure 9.4.

The similarity in the processing of the prime and target reflects task instruction, that is, subjects were merely silently reading one word at a time with no other requirements, making it plausible that very similar processing would be used to process all the words presented, because the task was the same for each word. It is interesting that both primes and targets elicited an N400, but there was no priming effect on the amplitude of the N400 for the second word. As in Experiment 1, subjects were kept naïve about the relationship between the first and second word, and the relationship had no bearing on task performance. It can be speculated that these task conditions made subjects less likely to focus attention on generating an expected set of words to facilitate the recognition of a subsequently-presented word. It is also likely that attention was not focused on determining whether the second word presented formed part of any expected set of words generated by the prime.

Another difference between the silent-reading and letter-search task was that the latter displayed a Slow Wave component for targets, but the Slow Wave component was not evident in the silent-reading task, indicating that the processing associated with the second word did not involve the scanning of long-term memory. This is consistent with the task demands, which did not require information to be held or retrieved in order to perform the task.

9.2.2. RELATEDNESS-JUDGEMENT TASK

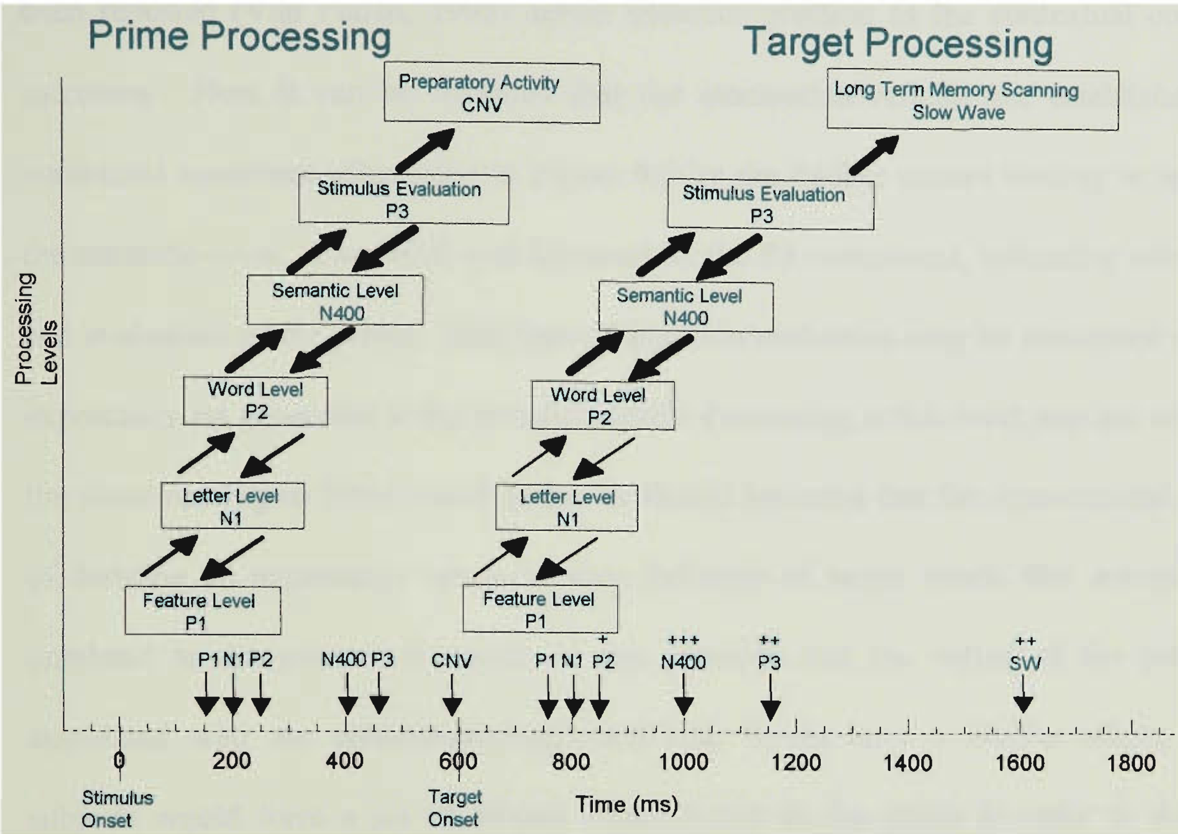


Figure 9.5. ERP processing interpreted in a modified version of the interactive activation model for the relatedness-judgement task used in Experiment 2. Thicker arrows indicate where the depth of processing is thought to be greater. Thinner arrows indicate lower levels of activation. The '+' sign reflects the rise, +++ the peak, and ++ the fall of the difference wave illustrated in Figure 8.5.

9.2.2.1. PRIME PROCESSING

As in the previous experiments, processing commenced with the P1 and there is clear visual evidence of an N1 component, reflecting the processing of visual feature information in order to form a representation of the letters at the letter level. This was followed by word recognition at the word level, reflected by P2. Development of the N400 component reflects increasing semantic-level activation, involving establishing word meaning and the activation of associates. The N400 to primes in the relatedness-judgement task was attenuated frontally compared with the silent-reading task, which may indicate that attention is now specifically directed to establishing as large an expectancy

set as possible through spreading activation to associated words. A similar attenuation has been reported (Van Petten, 1995) across sentence position as the contextual constraint increases. Here it can be assumed that the attenuation reflects the establishment of contextual constraint, illustrated in Figure 9.5 by the thicker arrows leading to and from the semantic-level. The N400 was followed by the P3 component, indicating attention to and evaluation of the prime. This type of attention/evaluation may be associated with the expectancy set generated at the semantic-level. Processing at this level was not evident in the silent-reading or letter-search tasks. It should be noted that the conventional manner of deriving an expectancy set is to vary the ratio of target words that are related or unrelated to the prime. However, it was assumed that the nature of the processing associated with the relatedness-judgement task would have a similar affect, that is, subjects would form a set of related words based on the prime in order to determine whether the target word was related to the prime word. This task-specific processing was depicted by thicker arrows leading to the stimulus-evaluation level (see Figure 9.5). The CNV amplitude was larger over the frontal midline region in the relatedness-judgement task than the silent-reading task. Enhanced preparatory activity is depicted by thicker arrows in Figure 9.5, indicating the greater relevance of prime processing to target processing. It could be speculated that CNV reflects activation of a 'buffer' mechanism to store relevant information in anticipation of a future event.

9.2.2.2. TARGET PROCESSING

Again, target processing commenced in a similar manner as with the prime, but there was an attenuation in P1 amplitude, indicating that a reduced level of activation was required to form a representation at the feature level (P1). A similar attenuation in processing appeared to occur at the letter level (N1). The apparent facilitation of processing is

indicated by the thinner arrows in Figure 9.5. The development of P2 reflects increasing word-level activity through bottom-up and top-down processing. There was a priming effect on P2 amplitude, that is, it was larger for related than unrelated target responses. The difference wave indicates that this is the point at which differences in related and unrelated target word processing commenced. This was depicted by a + sign above the P2 component in Figure 9.5. The top-down activation of associated words by the prime may have pre-activated a set of words that included the target word, leading to heightened activation at the word level relative to unrelated target words. The bias in the flow of information resulting in the priming effect on P2 amplitude is depicted by thicker arrows in Figure 9.5.

There was an increase in N400 amplitude for unrelated target responses and a greater attenuation for related target responses relative to the N400 elicited by prime responses. The difference wave indicates that this is the point of maximal difference in the processing of related and unrelated target words, indicated by the +++ sign above the N400 component label. The development of the N400 represents information being fed bottom-up from the word level and top-down to the word level, gradually increasing within-level activity at the semantic level. The increase in peak amplitude for unrelated target responses may indicate that greater between-level activity was used to determine whether there was any prior activation for the target word in the semantic-memory network, resulting from an expected set of words generated by the prime through spreading activation. This could be conceptualised as the 'integration process' commonly referred to (Brown & Hagoort, 1993; Chwilla, Hagoort, & Brown, 1998; Rugg, 1990; Rugg & Doyle, 1992; St. George, Mannes, & Hoffman, 1994).

There was a priming effect on N400 amplitude, that is, related targets elicited an

attenuated N400 relative to prime responses. The extent of the information being fed bottom-up from the word level and top-down to the word level - to produce maximum activation of processes at the semantic level - was reduced for related targets. Recognition of related targets presumably benefited from the expectancy set generated by the activation of prime word associates. The 'set' adopted by the subjects may have focused attention at the word and semantic levels, increasing the extent to which semantic associates were activated by the prime word. This view is supported by the priming effect on P2 amplitude. The bias in the flow of activation is indicated by thicker arrows in Figure 9.5.

The N400 was followed by a P3, which was larger in amplitude for related than unrelated target responses. The difference wave indicates that the residual difference in related and unrelated processing declined over the P3 latency range, indicated by the ++ sign above the P3 component in Figure 9.5. As the P3 develops, information may flow bottom-up from the semantic level to the stimulus evaluation level and top-down from this level to the semantic level. The peak may indicate maximum activation of processes involved in evaluating the specific relationship of the word-pair based on the representation established at the semantic level - related targets were associated with a heightened level of activation relative to that associated with unrelated targets. The nature of the task may require the explicit focusing of attention/evaluation to make a relatedness decision in order to perform the immediate overt task (Donchin, 1981). As with the P2, the P3 amplitude increased in response to related targets, and this may indicate that the semantic representation formed at the semantic level was consistent with an affirmative response.

Unlike the letter-search task, the Slow Wave amplitude here was larger for unrelated than

related targets, which may reflect task differences. That is, in the relatedness-judgement task the meaning of both the prime and target word, rather than just the letters, is required to be held/retrieved from long-term memory. Retrieval of the related word may be easier due to pre activation at the early stages of processing, reflected in the priming effect on P2, N400 and P3 amplitude. This is supported by the 'priming signature' which emerged in the difference wave for this task. The difference wave indicates that the residual difference in related and unrelated target word processing continues to the end of the epoch at a similar level to that associated with the stage of stimulus-evaluation processing.

The relatedness effect based on the differences wave suggests that differences in related and unrelated target word processing in the relatedness-judgement task commenced at the word level (+), peaked at the semantic level (+++), declined over the stimulus-evaluation level (++) and continued at that level during the scanning of long-term memory (++) to the end of the epoch. It should be noted that the difference wave for the silent-reading task did not display a distinct residual activation associated with relatedness processing.

9.3. EXPERIMENT 3

9.3.1. RELATEDNESS-JUDGEMENT TASK

Figure 9.5 above also represents the model proposed to account for the effects obtained in the relatedness-judgement task used in Experiment 3. The dynamics of the model are similar, as the tasks were essentially the same. The variations in Experiment 3 were the counterbalancing of tasks and a 20 % reduction in the number of stimuli used. These variations appear to have resulted in differences mainly associated with target processing. The reduced number of trials that were averaged to produce the ERP led to differences in the topography of the priming effect in the target N400 and P3. Also, priming effects on

the target P2 and Slow Wave amplitude fell short of significance statistically, but were in the same direction as the results obtained in Experiment 2. It could be that the pattern of activation along the pathways illustrated in Figure 9.5 changes as the number of trials increase. The developmental pattern of activation across the network can be conceptualised as an exponential curve, with the patter of activation stabilising as the number of trials increases.

In the relatedness-judgement task (Experiment 3) the difference waves appeared to commence and peak over the N400 (semantic level) latency range, declining over the P3 (stimulus evaluation) latency range and continuing at this level of activation over the Slow Wave (long-term memory scanning) latency range. Difference in processing associated with relatedness began to emerge at the semantic level, in contrast to Experiment 2 in which such differences commenced at the word level. The topographic and statistical differences between the relatedness-judgement tasks used in Experiments 2 and 3 indicated that subtle task differences influenced the flow of activation.

9.3.2. MEMORISATION TASK

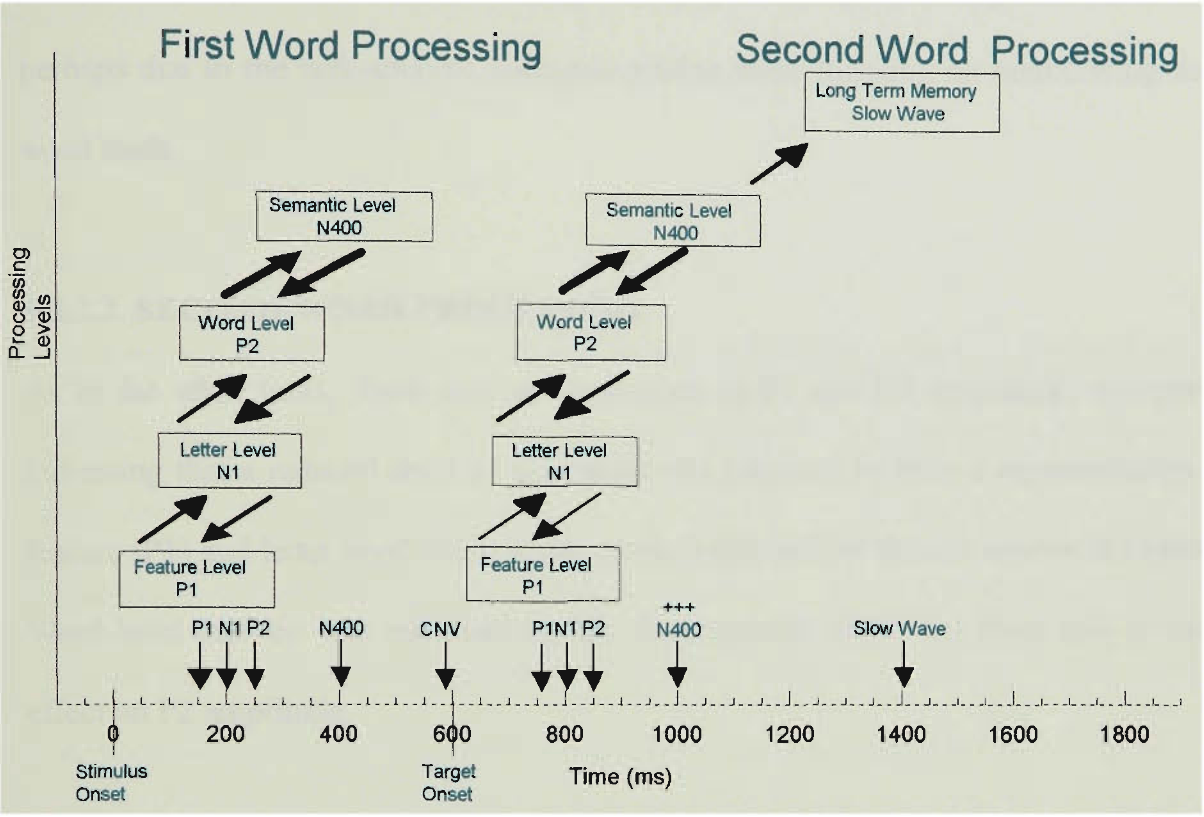


Figure 9.6. ERP processing interpreted in a modified version of the interactive activation model for the Memorisation Task used in Experiment 3. Thicker arrows indicate where the depth of processing is thought to be greatest. Thinner arrows indicate lower levels of activation. The '+++' reflects the peak of the difference wave illustrated in Figure 8.6.

9.3.2.1. FIRST-WORD PROCESSING

Again, processing commences with the gathering of information at the feature level (P1) and letter level (N1). The development of P2 through bottom-up and top-down processing indicates increasing word-level activity. Increasing semantic-level activation is reflected by the development of the N400 component. Although subjects were not informed about the relationship between the first and second word, as the number of trials increased attention may have been directed to the semantic level in order to establish an expectancy set through spreading activation. The thicker arrows leading to the semantic level reflect

attention focused on establishing an expectancy set of target words through the spreading of activation to semantic associates. Unlike the other tasks, the CNV did not appear to be elicited. This indicates a lack of preparatory processing in anticipation of the target, perhaps due to the task-specific demands arising from focusing on memorising the first word itself.

9.3.2.2. SECOND-WORD PROCESSING

As in the other tasks, there was an attenuation in P1 and N1 amplitude, interpreted as indicating that a reduced level of activation was required to form a representation at the feature (P1) and letter level (N1), respectively (indicated by thinner arrows in Figure 9.6). Word-level activity was indicated by the development of P2 but there was no priming effect on P2 amplitude.

There was a small priming effect on N400 amplitude, (i.e. related word < unrelated words). The difference wave displayed a distinct relatedness effect commencing and peaking over the N400 latency range (indicated by the +++ above the N400 component in Figure 9.6), followed by a return of activation to baseline level. In terms of the model, the extent of activation being fed bottom-up from the word level and top-down to the word level was reduced when the second word was related to the first. Attention was directed to determining whether the second word formed part of the expectancy set. The use of attention in this manner could be what is referred to as the integration process, which is usually described in more general terms. When attention is directed to determining whether the target word forms part of the expectancy set, recognition is facilitated for items consistent with the expected set of words generated by the first word. This effect is indicated by the thicker arrows leading to the semantic level in Figure 9.6.

Slow Wave amplitude displayed no significant difference between unrelated and related targets, indicating that bottom-up and top-down processing was similar for unrelated and related second words. That is, the meaning of the first and second word may have been held/retrieved from long-term memory, but as distinct units.

9.4. SUMMARY

This chapter interpreted the experimental findings associated with visual word recognition and semantic priming using the modified Interactive Activation framework proposed by Stoltz and Besner (1996). This provided a tentative insight into the processes used in visual word recognition and the temporal organisation of cognitive processing. It was assumed that the ERP components reflect stages of information processing and an attempt was made to link underlying cognitive functions with these stages of processing. It was clear from the modelling that many of the underlying cognitive processes, reflected by the ERP components, occurred for both primes and targets, and also that differences emerged between tasks. The differences between tasks were the result of how the underlying cognitive processes were utilised to preform the specific tasks, and this was depicted by the flow of activation within the proposed models.

CHAPTER 10

CONCLUDING REMARKS

Language comprehension emerges as a result of many underlying processes. This thesis set out to add to the body of knowledge relating to language processing, aiming to identify and describe the event-related potentials associated with some aspects of such processing. The focus was on the semantic-related N400 event-related potential.

Kutas and Hillyard (1980) originally reported the N400 effect, using a sentence paradigm in which words were presented *in seriatim*. The sentences differed with respect to the terminal word - in 75 % of sentences presented, the terminal word was congruent with the semantic context established by the sentence, and the remaining 25% were incongruent with the preceding context. It was reported that the terminal words elicited a posterior negative component between 300 and 600 ms post-stimulus onset. The N400 elicited by congruent terminal words displayed attenuation in amplitude compared with incongruent terminal words, and this is commonly referred to as the 'N400 effect'. In respect to sentence position, it has been reported that words occurring late in a sentence elicited a smaller N400 than those occurring in earlier sentence positions (Van Petten, 1995).

Although the N400 effect was originally observed in sentence tasks where semantic expectancies were violated, the N400 effect has also been reliably elicited in word-pair and word-list paradigms. Such paradigms have enabled the investigation of the N400 without confounds of syntactic constraints or complex contexts which may impact on the results obtained in sentence tasks. Tasks explored in these paradigms have included lexical decision (Bentin, McCarthy, & Wood, 1985; Holcomb, 1988; Silva-Pereyra,

Harmony, Villanueva, Fernandez, Rodriguez, Galan, Diaz-Comas, Bernal, Fernandez-Bouzas, Marosi, & Reyes, 1999), semantic categorization (Boddy & Weinberg, 1981; Deacon, Breton, Ritter, & Vaughan, 1991; McCarthy & Nobre, 1993; Young & Rugg, 1992) and phonological matching (Kutas & Van Petten, as cited in Ackles, Jennings, & Coles. 1988; Rugg, 1984; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980).

Several perspectives have been proposed regarding the role that the N400 plays in language processing. Initial interpretations suggested that the N400 reflected processing associated with lexical access or constructing a semantic representation of a word (Bentin, 1987; Kutas & Hillyard, 1989; Kutas & Van Petten, as cited in Ackles, Jennings, & Coles, 1988; Van Petten & Kutas, 1987). It has since been suggested that the N400 reflects post-lexical processing associated with semantic integration (Brown & Hagoort, 1993; Chwilla, Hagoort & Brown, 1998; Rugg, 1990; Rugg & Doyle, 1992; St. George, Mannes, & Hoffman, 1994). The literature has reported that N400 amplitude varies as a function of how easily a word representation can be integrated into the context in which it was presented (Dien, Frishkoff, & Tucker, 2000; Kutas, 1997). It has been suggested that the N400 effect reflects semantic expectancy, in addition to post-lexical processes that integrate word representations with the context (Chwilla, Brown, & Hagoort, 1995; Halgren, as cited in Scheibel & Wechsler, 1990; Hinojosa, Martín-Loeches, & Rubia, 2001; Holcomb, 1993; Weckerly & Kutas, 1999). It should be noted that De Groot (1984, 1985) reported a relatedness-proportion effect in a lexical decision task with a short stimulus onset asynchrony (SOA). This finding was supported by Hodgson (1991) who reported semantic-priming effects at short and long SOAs. It was concluded that the post-lexical meaning integration process could be fast-acting, suggesting that it is a mandatory process utilized for comprehension (Fodor, 1983). Also, Chwilla, Hagoort and Brown

(1998) reported an N400 backward priming effect in a lexical decision task using an interstimulus interval of 0 milliseconds. It was concluded that the N400 priming effect reflects an automatic integration process. However, Experiments 2 and 3 in this thesis showed differences in the magnitude of the N400 priming effect between tasks, and processing associated with this difference does not conform to the definition of automatic processing - which is considered to be fast, inflexible, and parallel, that does not require conscious attention or the depletion of the attentional resource(s). Controlled processing is considered to be slow, flexible, and serial, which requires conscious attention and draws upon the limited attentional resource(s) (Neely, 1977; Posner & Snyder, as cited in Solso, 1975; Shiffrin & Schneider, 1977). The research suggesting that the N400 priming effect reflects an automatic integration process challenges the either/or definition of automatic and controlled processing. This implies that the controlled process of integration can display some characteristics of an automatic process.

The experiments carried out in this thesis used ERPs to outline the time-course of word comprehension/semantic processing in the interactive activation framework. Hinojosa, Martín-Loeches and Rubia (2001) suggest that semantic processing can be divided into three basic subprocesses. Initially, presemantic analysis occurs, commonly referred to as lexical access. This process activates a subset of compatible entries in the mental lexicon. The best candidate is chosen during lexical selection. Finally, the lexical item selected is integrated into a higher-order representation based on the semantic and syntactic constraints of the context.

The aim of this thesis was to explore the extraction of meaning in the reading process using information derived from the ERP. The issues addressed related mainly to the

processing reflected in the N400 component. Data analysis techniques (principal components analysis and difference waves) and experimental design techniques were employed to address the issues of component identification and separation, as well as component processing. Specifically, these techniques assisted in addressing the issue of component overlap between the N400 and P3. The role played by other ERP components was also explored in order to develop a better understanding of N400 processing in the broader context of the ERP signature.

Experiment 1 replicated the delayed letter-search task used by Kutas and Hillyard (1989). The aim of their experiment was to determine whether a non-semantic task would elicit a priming effect on N400 amplitude. The design of the experiment also enabled them to address the issue of whether the priming effect on N400 amplitude occurs independently of changes in P3 amplitude and latency. Kutas and Hillyard (1989) reported a priming effect on N400 amplitude in the delayed letter-search task even though it was assumed to be a non-semantic task. They concluded that the priming effect on N400 amplitude reflected the automatic processing of semantic information. The delayed letter-search task was replicated here because the findings seemed contrary to the growing body of literature which suggests that the N400 amplitude elicited by the target is enhanced in tasks encouraging semantic analysis, and this is assumed to reflect post-lexical integration processing.

In Experiment 1, the behavioural results indicated that responses were faster for related than unrelated word pairs regardless of letter presence. The components identified using principal components analysis were P1, P2, N400, CNV and a Slow Wave. Of these, P1, P2 and N400 displayed a component peak for both prime and target over a similar time

frame after stimulus onset. This implied that the underlying cognitive processes associated with prime processing are not distinct from those used to process the target. This may have been assumed in the past rather than being specifically addressed, but principal components analysis proved to be a useful data-analysis technique to show that this was indeed the case. The data-analysis techniques of within-subject repeated-measures ANOVA, and difference waveforms, failed to reveal a priming effect in N400 amplitude, however a priming effect did emerge for the Slow Wave component.

It was concluded that the processing underlying the N400 effect must be consciously controlled because a truly automatic process would have resulted in a priming effect on N400 amplitude regardless of the task. Although Kutas and Hillyard (1989) assumed that the delayed letter search task was a non-semantic task, the priming effect on Slow Wave amplitude and reaction time suggested that semantic information was accessed. Overall, it was concluded that the priming effect on N400 amplitude might not have occurred because the nature of the task did not require the integration of the prime and target in order to derive a higher-order meaning based on the context. Although the experimental design eliminated the P3 component, the lack of a priming effect on N400 amplitude made it impossible to conclude whether such an effect occurs independently of changes in P3 amplitude and/or latency.

The aim of Experiment 2 was to increase the extent of semantic analysis in order to elicit a priming effect on N400 amplitude. The design of the experiment compared a silent-reading task with a relatedness-judgement task. This design again addressed the issue of whether the priming effect on N400 amplitude occurs independently of changes in P3 amplitude and/or latency. The multi-tasking experimental design enabled the assessment

of processing differences between tasks whilst retaining a within-subjects data analysis technique. The silent-reading task did not require an overt response and the semantic relationship between primes and targets was not explicitly task relevant, whereas the relatedness-judgement task required subjects to explicitly attend to the semantic relationship between word pairs in order to make an overt judgment about whether the target was related to the prime. It was assumed that the silent-reading task would elicit a priming effect on N400 independently of the P3 component and this was to be compared with the priming effect on N400 and P3 in the relatedness-judgement task.

Behavioural results were only obtained for the relatedness-judgement task. Reaction times to related targets were significantly faster than to unrelated targets, indicating that a facilitatory priming effect occurred in the related word-pair condition. The components identified using principal components analysis were similar between tasks and to those identified in Experiment 1. The components identified for analysis were P2, N400, P3, CNV and a Slow Wave. P2, N400 and P3 displayed a component peak for both prime and target over a similar time frame after stimulus onset in the relatedness-judgment task. This was the same in the silent-reading task, except for the P3. The relatedness-judgement task displayed a distinct priming effect on P2, N400, P3 and Slow Wave amplitude. The difference wave for the relatedness-judgement task displayed a broad residual effect of relatedness commencing at the onset of the P2 component, peaking over the N400 latency range, then stabilising over the P3 and Slow Wave latency ranges. The silent-reading task displayed only a slight priming effect in N400 amplitude, and the difference wave visually indicated that the effect was not robust.

The results supported the argument put forward following Experiment 1 that the

processing underlying the N400 effect does not reflect a truly-automatic process because such a process would have resulted in a robust priming effect on N400 amplitude in the silent-reading task. It is assumed that the presence of the N400 in the silent-reading task, for both primes and targets, reflects access to the semantic representation of the words and possibly activation spreading to associated words. However, the task could have been efficiently performed without the need to integrate the target and prime into a meaningful interpretation based on the context. On the other hand, the relatedness-judgement task explicitly required the integration process in order to perform the task. The broad nature of the relatedness effect in the relatedness-judgment task indicates that multiple processes were involved in the relatedness effect. There was no distinct P3 component elicited in the silent-reading task, however the priming effect on N400 amplitude was not robust. The priming effects on P2, N400, P3 and Slow Wave amplitude for targets in the relatedness-judgment task displayed differences in topography, indicating that these effects were distinct. However, the broad affect of relatedness clearly visible in the difference wave form for this task suggests that different mechanisms may have jointly contributed to the observed priming effects.

Again, it was difficult to determine whether the N400 effect was distinct from the P3 effect based on experimental design, due to the lack of a robust priming effect on N400 amplitude in the silent-reading task. For this reason, the experimental design in Experiment 3 was structured to try to clarify this issue. A memorisation task was used in this experiment, not only to increase the extent of semantic analysis (compared with the silent-reading task), but to induce the use of the integration process. In this task subjects were instructed to memorise the word pairs as they appeared on the screen in order to perform a subsequent recognition-memory task. Subjects were kept naïve about the

semantic relationship between the word pairs. The multi-tasking approach was retained – subjects were also required to perform a relatedness-judgement task. Task order was counterbalanced, but the number of stimuli presented was reduced in order to reduce fatigue.

The behavioural results in the relatedness-judgement task were similar to those in the previous experiment. That is, mean reaction times for related targets were significantly faster than those for unrelated targets. This clearly indicated that a facilitatory priming effect had occurred in the related word-pair condition. In the memorisation task, recognition for previously-presented related word pairs was significantly greater than previously-presented unrelated word pairs. The components identified using principal components analysis were the same as those from Experiment 2: P2, N400, P3, CNV and a Slow Wave. In the relatedness-judgement task the P2, N400 and P3 again displayed a component peak for both prime and target over a similar time frame after stimulus onset. The memorisation task elicited similar components, except for the P3 and CNV. The relatedness-judgement task displayed a significantly-larger target-priming effect on N400 and P3 amplitude. The distribution of the priming effect on N400 amplitude was parietal, which differed from Experiment 2 (in which it displayed a vertex maximum). The P2 and Slow Wave components displayed a priming effect that did not reach statistical significance. As in Experiment 2, the difference waveform associated with the relatedness-judgement task displayed a broad residual effect commencing at the onset of the N400 component, peaking over the N400 latency range, and stabilising over the P3 and Slow Wave latency ranges. The memorisation task displayed only a target-priming effect on N400 amplitude and the difference waveform visually indicated that a relatively short effect occurred.

The larger priming effect in the relatedness-judgement task than the memorisation task again shows the finding common across experiments, indicating that the processing underlying the N400 effect is not truly automatic. Again, the priming effect should have been of a similar magnitude in both tasks if the processing underlying N400 was truly automatic. The reduced awareness of the semantic relationships in the memorisation task was due to task instruction, and may account for the difference in the magnitude of the priming effect between tasks. This is a consistent finding, not only in the experiments conducted in this thesis, but also in the literature. That is, the magnitude of the priming effect on N400 amplitude has been linked with the extent to which the task encouraged subjects to attend and utilise semantic information (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Deacon, Breton, Ritter, & Vaughan, 1981; Kellenbach & Michie, 1996; Rugg, Furda, & Lorist, 1988). It should be noted that the N400 occurred for primes in all tasks. This may represent an automatic aspect of processing involved in forming a semantic representation of the word which includes the activation of associated words. The N400 effect is thought to reflect semantic expectancy as well as the integration of word representations with the current context (Federmeier & Kutas, 1999; Weckerly & Kutas, 1999). Perhaps the implicit use of the semantic relationship between word pairs in the memorisation task did not generate the same level of activation associated with expectancy and integration processing that occurred in the relatedness-judgement task.

Interestingly, the N400 was elicited by primes and targets in all tasks, regardless of whether a priming effect occurred in N400 amplitude for targets. It has been suggested that the N400 represents both automatic and controlled aspects of processing (Ziegler, Besson, Jacobs, Nazir, & Carr, 1997; Hinojosa, Martín-Loeches, & Rubia, 2001). The

experimental findings can be interpreted in this context as follows: The letter-search task elicited an N400 for both prime and target, and this may represent the automatic activation of a semantic representation of the word being processed, and possibly the spreading of activation to associated words. The silent-reading task displayed a similar outcome, except that the N400 elicited by both primes and targets appeared larger than that in the letter-search task. This suggested that the level of semantic representation/spreading activation was greater for words processed in the silent-reading task. When interpreting the findings of the relatedness-judgement task, it is considered that the prime generates an N400 indicating semantic representation, and the spreading of activation to associated words forms the expectancy set of related words in anticipation of the target. The N400 elicited by targets displayed a relatedness effect, in which responses to related-word targets were attenuated compared with unrelated-word targets. This has been described as an index of the integration of word representations in the context provided by the prime. The 'integration process' itself has not been clearly defined. It is proposed here that the integration process occurs when attention is directed to the expectancy set (which may be automatically generated), and information from that set is then used in the recognition of the target stimulus. The preactivation of information related to the target means that less activation is required for its recognition, reflected in the attenuation of the N400 to related targets. From the large body of N400 research, it would appear that the priming effect is largest when (i) expectancy is generated and (ii) performance of the task requires the use of the expectancy generated. Whilst the N400 has been associated mainly with language, future research may attempt to compare tasks that generate non-verbal and verbal forms of expectancy in order to determine if the processing is compatible between tasks.

Language processing was modelled in Chapter 9 to provide a basic interpretation of the

ERP components and make use of the good temporal resolution that this method offers. As mentioned previously, it was assumed that the component peaks indicate stages of processing, a view commonly accepted in the literature. However, it should be noted that the component peaks may merely mark the order of processes rather than the temporal organisation of these processes. The model was based on that of Stoltz and Besner (1996), who modified the Interactive Activation framework originally proposed by McClelland (1989). The model provides a framework for three basic subprocesses of semantic processing – lexical access, lexical selection and integration. The initial component complex elicited by all tasks and both primes and targets was the P1N1, which consistently displayed a parietal topography. These components were assumed to reflect prelexical processes that activate feature (P1) and letter (N1) entries that are compatible with the mental lexicon. The time course for this processing was between 80 and 200 ms.

The selection of the most consistent word form was reflected by the P2, which was elicited in all tasks and for all stimuli, with a peak latency of approximately 240 ms. This component was attenuated for related targets in the relatedness-judgement task used in Experiment 2. It has been suggested that access to word meaning occurs around the time frame of the P2 component (Posner, 1998). However, it was concluded that recognition of the related targets at the lexical selection stage required less activation due to prior activation by prime associates. This does not necessary imply that word meaning was accessed.

The post-lexical process associated with forming a semantic representation of the stimulus words was reflected by the N400 component and took place around 275 to 440 ms. This component was elicited by both primes and targets in all tasks. It was concluded that the

mere presence of the N400 reflects the automatic activation of word meaning. However, the priming effect on N400 for targets was assumed to provide an index of the integration of word meaning within the context in which the stimulus was presented. The experiments clearly demonstrated that the integration process is task-dependent.

Processing levels/stages additional to those proposed by Stoltz and Besner (1996) were constructed to accommodate the data. These included stimulus-evaluation, long-term memory scanning and preparatory activity. Stimulus evaluation was reflected by the P3 component (400 - 750 ms), which occurred for both primes and targets, but only in the relatedness-judgement tasks. This task-dependent processing followed the N400 component and displayed a priming effect for targets. The relatedness-judgement task was the only task that required an immediate overt response. Processing associated with the P3 was interpreted as stimulus evaluation to achieve contextual closure/resolution in anticipation of an immediate response (Friedman, Simson, Ritter, & Rapin, 1975). The process underlying the Slow Wave component reflected the retrieval of the prime and target from long-term memory. This type of processing only occurred for target words, commenced at approximately 750 ms and continued until the end of the epoch. Prime words elicited a CNV, which reflected preparatory activation in anticipation of the target stimulus. The CNV was maximal at the end of the prime epoch and continued on into the initial period of the target epoch. CNV was elicited in all tasks, except for the memorisation task. Hence it was argued that the strategy adopted in the memorisation task was to memorise the stimuli as isolated units.

Overall, the data analysis techniques of principal components analysis and difference waves, as well as the experimental design techniques, assisted in addressing the issues of

component identification, component separation and component processing. One of the major outcomes was the use of principal components analysis to illustrate that the underlying processes used to process the prime are similar to those used to process the target. It was clearly shown that the N400 effect occurs independently of processing associated with the P3 component. The difference in the magnitude of the N400 effect between tasks demonstrated that the relatedness effect is task-dependent and therefore does not reflect a truly automatic process as defined by Posner and Snyder (1975). However, the mere presence of the N400 in the absence of an N400 effect may reflect the automatic extraction of meaning associated with the stimulus presented. In the case of words, this may result in the activation of associated words. Intuitively this seems sensible, because humans are constantly trying to interpret their environment. However, the priming effect on N400 amplitude for targets was assumed to provide an index of the integration of word meaning. Attention needs to be directed to this type of processing in order to accommodate meaning in the context in which the stimulus was presented. The automatic and controlled descriptions of the processing underlying the N400 and the priming effect, respectively, are consistent with the current literature (Ziegler, Besson, Jacobs, Nazir, & Carr, 1997; Hinojosa, Martín-Loeches, & Rubia, 2001).

In conclusion, this study was carried out to explore how meaning was extracted from visually-presented words. A systematic approach using specific design and data techniques enabled conclusions to be made regarding automaticity, component overlap and general processing. An expanded model of the processing indicated by the ERP signature provided insight into the sequential and temporal nature of processing used to perform the tasks. It is hoped the others will be encouraged to use similar techniques when investigating the complex nature of the cognitive processing involved in reading.

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APPENDICIES

The following refer to files on CD-rom attached to the inside back cover of this thesis.

APPENDIX 1: ETHICS CONSENT FORM.

APPENDIX 2: STATISTICS FOR EXPERIMENT 1

APPENDIX 2.1. ANALYSIS 1

Appendix 2.1.1. Repeated measures ANOVAs and planned contrasts.

Appendix 2.1.2. Principal Components Analysis.

APPENDIX 2.2. ANALYSIS 2

Appendix 2.2.1. Principal Components Analysis

APPENDIX 2.3. ANALYSIS 3

Appendix 2.3.1. Repeated measures ANOVAs and planned contrasts.

Appendix 2.3.2. Principal Components Analysis.

APPENDIX 3: STATISTICS FOR EXPERIMENT 2

Appendix 3.1. Repeated measures ANOVAs and planned contrasts.

Appendix 3.2. Principal Components Analysis.

APPENDIX 4: STATISTICS FOR EXPERIMENT 3

Appendix 4.1. Repeated measures ANOVAs and planned contrasts.

Appendix 4.2. Principal Components Analysis.