NEUROPHYSIOLOGICAL AND BEHAVIORAL CORRELATES

OF LANGUAGE PROCESSING AND

HEMISPHERIC SPECIALIZATION

Christina M. McCann, M.S.

APPROVED:

Major Professor

Committee Member

Committee Member

Committee Member

Chair of the Department of Psychology

Dean of the Robert B. Toulouse School of Graduate Studies

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The purpose of this study was to examine language organization in the brain by using a series of three tasks concurrent with event-related potentials (ERPs) to investigate both hemispheric differences and interhemispheric interactions. Experiment 1 was a lexical decision task with semantic priming with four conditions for unilaterally-presented targets: (1) primed words (2) unprimed words (3) pronounceable non-words and (4) non-pronounceable non-words. Participants determined whether the target was a word. ERPs, including the late positive component (LPC) and the N400, were measured to examine neurophysiological correlates of cognitive processes that occurred during the tasks. Experiment 2 addressed methodological concerns by changing the task from primed lexical decision to primed delayed matching, where participants determined whether a second target stimulus matched the first. By delaying the decision-making process, component overlap between the LPC and N400 should be reduced. Experiment 3 used only word stimuli in a primed delayed matching task with bilateral presentations of redundant or non-identical targets to further explore interhemispheric effects.

A total of 49 undergraduates participated in one of three experiments. Behavioral and ERP results illustrate the facilitative effects of semantic priming for both hemispheres. An overall right visual field (RVF) advantage emerged for behavioral, but not ERP, measures indicating left hemisphere (LH) superiority for these language tasks. Both Experiments 1 and 2 revealed a strong hemispheric difference in N400 amplitudes for processing of pronounceable versus non-pronounceable non-words, consistent with previous behavioral findings supporting LH capability and right hemisphere (RH) inability for grapheme-to-phoneme processing. Experiment 2 reduced component overlap, but also changed the pattern of ERP findings for the four conditions. Behavioral priming effects were clearly indicated with bilateral different presentations in Experiment 3, while ERP evidence appeared to support interhemispheric cooperation.

Overall, the findings from this study support a relative rather than absolute hemispheric specialization for language processing. Despite an overall RVF (LH) advantage, both hemispheres were capable of performing the tasks and benefited from semantic priming.

NEUROPHYSIOLOGICAL AND BEHAVIORAL CORRELATES OF LANGUAGE PROCESSING AND HEMISPHERIC SPECIALIZATION

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Christina M. McCann, M.S.

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CHAPTER I

INTRODUCTION

Many unanswered questions remain regarding how the brain processes language. The goal of this study is to examine language organization in the brain by using lateralized lexical decision with associative priming to investigate both hemispheric differences and interhemispheric interactions. During a lexical decision task, a string of target letters is shown briefly, and may be preceded by a prime word. The participant is to determine whether this target stimulus is a word. Lexical decision performance to words improves when the target is preceded by an associated prime. Associative priming occurs when a pair of semantically related words (e.g., KING-QUEEN) is presented sequentially. Event-related potentials (ERPs) were used to examine neurophysiological correlates of the cognitive processes that occur during semantically-primed lexical decision and delayed matching. Neurophysiological data complements behavioral data that only offers information about the end result of language processing. The use of ERPs allows a closer look at different stages of language processing as they occur during discrete points in time. Some of the key questions that were addressed by this study include: (1) Do the left and right cerebral hemispheres differ in their lexical-semantic organization? (2) Do the cerebral hemispheres differ in their processing strategies (e.g., serial versus

gestalt)? (3) Can ERP measures distinguish independent hemispheric processing from interhemispheric cooperation?

LIST OF ABBREVIATIONS USED:

RH = right hemisphere
LH = left hemisphere
LDT = lexical decision task
ERP = event-related potential
RVF = right visual field
LVF = left visual field
BVF = bilateral visual field
RVFA = right visual field advantage
AW = associated word
UW = unassociated word
PNW = pronounceable non-word
NPNW = non-pronounceable non-word
LPC = late positive component
T1 = first target
T2 = second target
IA = identical associated
IU = identical unassociated
DU = different unassociated
LURA = LVF unassociated/RVF associated
LARU = LVF associated/RVF unassociated

Language and Hemispheric Specialization

Studies of various patient populations and normals have contributed to current understanding of left hemisphere (LH) involvement in various language operations. Aphasia is a disorder of language evident in speech, writing, or reading subsequent to injury to the brain area(s) specialized for these functions. It has been well documented that right-handed aphasia patients commonly have lesions or damage in the LH, resulting in different types of aphasia depending upon the location of the lesion (Benson, 1994; Carlson, 1991; Kolb & Whishaw,

1990). However, approximately 30% of left-handers have been found to have the principle language functions either localized to the right hemisphere (RH) or represented bilaterally (Rasmussen & Milner, 1977; Segalowitz & Bryden, 1983; Steinmetz, Volkmann, Jancke, & Freund, 1991). Converging evidence from split-brain patients (Hellige, 1990; Sperry, 1985) as well as research with brain-damaged deaf signers (Bellugi, 1992) also supports relative left hemispheric specialization of language. In addition, brain imaging techniques (e.g., fMRI, PET, SPECT, EEG) and behavioral measures (e.g., reaction times and error percentages elicited by tasks designed to assess particular stages of language processing) have illustrated LH superiority for specific types of language functioning in neurologically normal individuals (Clarke, 1995; Petersen, Fox, Posner, Mintun, & Raichle, 1988; Rugg, Kok, & Fischler, 1986), which will be discussed later in more detail.

Evidence from split-brain patients indicates that the RH does have linguistic capabilities including comprehension of written and spoken speech, although its capabilities are inferior to that of the LH (Zaidel, 1985). The RH is also specialized for some aspects of language processing such as perception of mood and voice intonation (Heilman, Scholes & Watson, 1975; Tompkins & Mateer, 1985), prosody (tone) of speech (Shapiro & Danly, 1985; Tucker, Watson & Heilman, 1977), and comprehension of nonverbal humor (Gardner, Ling, Flamm, & Silverman, 1975). Chiarello, Burgess, Richards, and Pollock (1990) have found evidence for a RH advantage when categorical, rather than

associative, priming is used in a lexical decision task where both prime and target letter strings are lateralized to the same visual field. Categorical priming occurs when the prime and target are from the same semantic category, such as CHERRY-BANANA, while associative priming occurs when the prime and target are semantically related, such as BEE-HONEY. Thus, while the LH is superior for most language functions, the RH possesses language processing abilities and even has better performance over the LH for some aspects of language functioning.

Functional Models Accounting for Behavioral Laterality Findings

First, behavioral tasks that are frequently employed in studies of language processing will be discussed. The lexical decision task (LDT) is an experimental paradigm where a stimulus consisting of a string of letters is presented tachistoscopically to the center, left, right, or both visual fields (VFs). The participant then decides whether the letter string is a word (e.g., HEAD) or a non-word (e.g., HEAK). Because the LH is more specialized for language processing, a right visual field advantage (RVFA) is found for lexical decision tasks (as described above). It has been well established that performance during lexical decision is enhanced when semantic priming is used (Becker, 1979, 1980; Foss, 1982; Meyer & Schvaneveldt, 1971; Neely, 1977). Accuracies and response times improve when target words (e.g., KING) are preceded by a primary word associate (e.g., QUEEN), than if the target is preceded by an unrelated word (e.g., PEAR). Findings from lateralized LDTs with associative

priming indicate that the semantic organization of the LH is characterized by strong connections between highly-associated words, and the RH by more loosely-associated words (Chiarello, 1985; Chiarello, et al., 1990; Burgess, Richards, & Pollock, 1990; Chiarello, Senehi & Nuding, 1987; Clarke, McCann, & Zaidel, in press; Neely, 1977; Zaidel, 1983).

The concept of relative and absolute specialization provides a framework for several functional models that support behavioral laterality findings. Certain tasks, such as lexical decision, can be accomplished by both hemispheres, although performance may not be equal, reflecting relative hemispheric specialization. Other tasks, such as dichotic listening to consonant-vowel syllables, can only be performed by one hemisphere (in this case the LH), showing absolute specialization for that hemisphere. Zaidel (1983) proposes two models, based on research with split-brain patients, to interpret laterality findings from lateralized tasks where stimuli are presented to one visual field, ear, or hand. The first of these, the callosal relay model, implies absolute hemispheric specialization. For example, if a stimulus is presented to the unspecialized hemisphere, the information will have to travel across the corpus callosum in order to be processed by the specialized hemisphere. In normals, lateralization of stimuli to the unspecialized hemisphere would slow processing and decrease accuracy relative to trials where the stimuli is lateralized directly to the specialized hemisphere. For split-brain patients, who have had the cerebral hemispheres disconnected by complete transection of the cerebral commissures,

stimuli will be processed quickly and accurately when lateralized to the specialized hemisphere. However, when stimuli are presented to the unspecialized, disconnected hemisphere, they will not be processed accurately and there will be a large laterality effect.

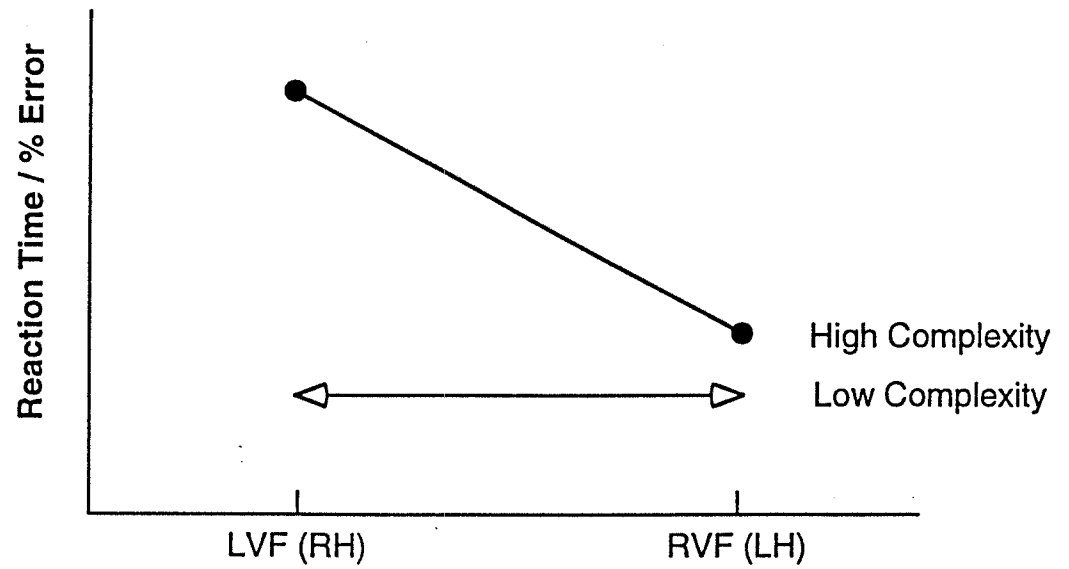
Zaidel's second laterality model of information processing, the direct access model, concerns relative hemispheric specialization. That is, both hemispheres can do a particular task, although they may differ in their abilities. For tasks that are processed in a direct-access fashion, the hemisphere that initially receives the stimulus, regardless of the specialization, will process the information. Both cerebral hemispheres of split-brain patients and normals are able to perform lexical decision with concrete, imageable targets and pronounceable non-words (Zaidel, 1983). Because there was evidence of a small RVFA for split-brain patients and normals, this task appears to utilize direct-access processing (i.e., both hemispheres are capable of doing the task independently). Additional evidence for direct-access processing is found in a pattern of experimental results referred to as "processing dissociation". This pattern occurs when there is an interaction of VF and some task variable (such as level of task complexity), suggesting independent processing. For example, direct access processing is implied when a task of low complexity is performed equally well by both hemispheres, but as the complexity level increases, one hemisphere outperforms the other (see Figure 1). In this case, both hemispheres are capable of doing the task independent of one another, and no information is

seemingly transferred to the less adequate hemisphere, resulting in superior performance of one hemisphere (see Zaidel, 1983; and Zaidel, Clarke & Suyenobu, 1988 for more detail) (see Figure 1). Zaidel (1985) also reviewed several studies that investigated RH involvement in language processing and concluded that the normal RH does not have certain phonological capabilities that are present in the LH. For example, a dichotic listening task with nonsense consonant-vowel (CV) syllables (i.e., /BA/, /PA/, /TA/) can only be performed by the left hemisphere (for the majority of right-handed individuals) and thus requires callosal relay for left ear stimuli that are lateralized to the RH. The laterality measure in this case shows the influence of hemispheric differences in specialization and costs of interhemispheric transfer. So, callosal relay and direct access models can be considered to exist at opposite extremes of a continuum for language processing, ranging from absolute to relative hemispheric specialization elicited by particular task demands. The majority of tasks likely engage both hemispheres while making use of callosal transfer and can be classified as eliciting processes that exist somewhere in the middle of this continuum.

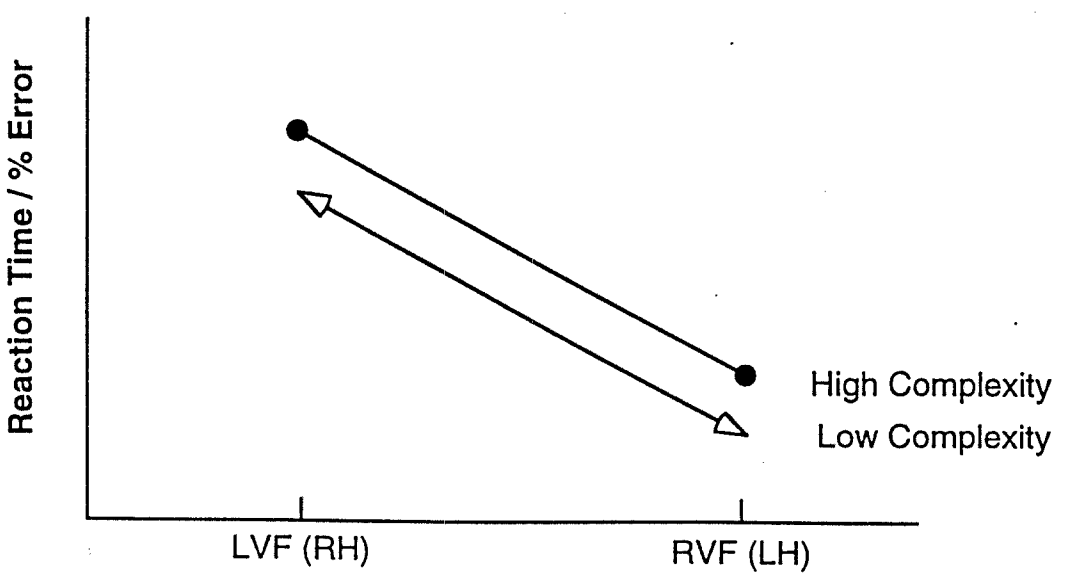
Zaidel (1989) presents a dual route model of lexical access for reading a word aloud and its relevance to differences in language processing in the cerebral hemispheres. One route involves direct lexical access through orthography (lexical route) and subsequent retrieval of the phonological form of the word (addressed phonology). The second route (non-lexical) involves

Figure 1

VF x task complexity: Expected patterns for direct access versus callosal relay models



Processing Dissociation: Direct Access Model



Lack of Interaction: Callosal Relay Model

sounding out the word (or letter string), which the RH is unable to do (assembled phonology). The RH's inability to use this second route may be associated with word length effects (LH advantage when processing words longer than four letters; Zaidel, 1989), reflecting the RH's use of visual recognition (lexical route).

Interhemispheric Interaction Models

Some tasks are best performed by dividing the processing between the hemispheres. This view is supported by findings where bilateral (i.e., across VFs) comparisons are more accurate and faster than unilateral VF (i.e., within a VF) comparisons (Banich & Belger, 1990; Belger & Banich, 1992). These findings can be interpreted as indications of interhemispheric cooperation with increased task demands, which differs from the processing dissociation pattern that supports direct access processing (the dominant hemisphere outperforms the other hemisphere as task demands increase in this case). Eng and Hellige (1994) also found evidence supporting interhemispheric collaboration. Fewer errors were recorded with bilateral (as compared to unilateral) presentation of pronounceable and non-pronounceable triads of letters to be identified.

Mohr, Pulvermuller, Rayman, and Zaidel (1994) further support the notion of interhemispheric cooperation through their findings involving bilateral-redundant presentations of stimuli for a lexical decision task. An advantage for bilateral, as compared to unilateral, stimulus presentations was found for a group of normal subjects. If the hemispheres do cooperate, then split-brain patients should not show such an advantage since this information cannot transfer; this

prediction was confirmed by Mohr et al. (1994) with one split-brain patient. Thus, unilateral lexical decision appears to be processed in a direct-access fashion, but interhemispheric interactions are still possible as demonstrated by the bilateral-redundant findings.

Although relative hemispheric specialization (direct-access processing) assumes independence of the left and right hemispheres in processing, interhemispheric cooperation may occur subsequent to the pre-lexical or perhaps even lexical stages of language processing as discussed by Chiarello (1988).

Lateralized Lexical Decision

Lateralized LDTs are employed to examine hemispheric differences in the processing of visually-presented words and non-words. By lateralizing the stimulus to the left or right visual hemifield, it is assumed that the opposite hemisphere processes the information initially (before callosal transfer). This is because the visual system is anatomically organized such that information in the left visual half field is lateralized to the RH, and vice versa (Carlson, 1991). Furthermore, a RVFA has been established for lexical decision, indicating a LH superiority for determining whether the target stimulus is or is not a word (Chiarello, 1988). This pattern of results is ambiguous relative to Zaidel's (1983) conceptualization of a direct-access task. Merely having a LH advantage does not necessarily indicate direct-access nor callosal-relay because RH ability (or inability) also needs to be determined. Zaidel (1989) found that split-brain patients can do LDT whether stimuli are presented to the LVF (RH) or RVF (LH),

supporting direct-access processing because both hemispheres are capable of doing the task independently. In addition, processing dissociations were found in normals where VF interacts with other variables such as word length, concreteness, response hand, and stimulus-onset asynchrony [(SOA)-the duration of time from one stimulus onset to the next, such as onset of a prime to onset of a target], to name a few. Such evidence in support of relative hemispheric specialization for language processing indicates that the RH does have language organization, but it is more limited than the LH. Zaidel (1985) highlights one of the major hemispheric differences in processing of word/non-word stimuli. Namely, the RH does not have grapheme-to-phoneme conversion capabilities. Consequently, the RH appears to process letter strings "ideographically", meaning that words are processed orthographically, without phonological translation (Cohen & Freeman, 1978; Krueger,1975; Zaidel & Peters, 1981). Mohr, et al. (1994) report a LH advantage, and an even greater bilateral advantage, for lexical decision when the target stimulus is a word. However, no hemispheric asymmetry was found for non-word targets across all three conditions (i.e., RVF, LVF, BVF). It appears as though phonological translation of non-words would not facilitate processing in this case, so the LH loses its advantage over the RH.

Lexical decision studies have revealed an overall LH advantage, but the RH can also perform these tasks, and even enhance LH performance when both hemispheres receive the same stimuli at once. These findings do not support

strict applications of callosal-relay nor direct-access processing, but rather they seem to reflect interhemispheric cooperation.

Lateralized Lexical Decision with Associative Priming

There is evidence that behavioral measures from lexical decision reflect hemispheric differences in pre-lexical, lexical and even post-lexical operations (Chiarello, 1988). Chiarello (1988) reviewed visual hemifield research relevant to lexical lateralization, based on early and later stages of information processing. Early, or pre-lexical, processes reflect visual analysis and encoding, while later stages involve more complex cognitive operations such as retrieval of lexical information and comprehension. Post-lexical processes reflect the actual decision stage of the LDT (e.g., determination of whether the stimulus is a word).

Variables affecting (pre-lexical) encoding of stimuli include stimulus orientation (vertical stimulus orientation lowers accuracy in the LH), and word length (increased word length increases reaction time in the RH, which is hypothesized to use serial encoding) (Chiarello, 1988). Young and Ellis (1985) found evidence for different encoding processes based on which hemisphere receives the input, and what type of stimuli is processed. They reported decreased efficiency in the RH when processing longer words and non-words. This finding is consistent with the notion that the RH processes in a serial manner, with letter-by-letter encoding, and the LH encodes information as a perceptual unit, rather than one letter at a time. However this interpretation is in direct opposition with the viewpoint presented by Zaidel and Peters (1981).

Based on experiments conducted with two commissurotomy patients, Zaidel and Peters (1981) conclude that the RH can read by recognizing words as visual gestalts, as opposed to serial processing of the individual letters. There could be an interaction with task complexity that has not been closely examined. In other words, targets with fewer letters may allow the RH to process more quickly, mimicking "gestalt" processing, while longer targets increase RH reaction time (as compared to the LH) leading one to conclude that serial processing is taking place.

Chiarello (1988) discusses word frequency (high versus low usage) in terms of the lexical stage of processing, that is, when the lexicon (memory store of words) is accessed. There was no significant interaction between VF and word frequency, which does not support the idea that the RH has a different lexicon made up of mainly frequently used words. However, this does not necessarily imply that there is only one lexicon that is located in the LH. For instance, according to the direct-access model, there should be two lexicons (one for each hemisphere) based on the assumption of independent hemispheric processing.

Post-lexical processing in word recognition tasks appears to diverge for the cerebral hemispheres because of hemispheric asymmetries in lexical decision (i.e., LH outperforms RH) (Chiarello, 1988). By adding semantic priming to lateralized lexical decision tasks, hemispheric differences in semantic organization can be further investigated. For instance, associative priming (e.g.,

BEE-HONEY, KING-QUEEN) leads to faster and more accurate responses in LDTs, as compared to unrelated priming (e.g., CHAIR-HONEY) for both hemispheres (Clarke & Zaidel, 1994; Neely, 1977; Zaidel et. al., 1990). Specific examples of priming effects include 1) significantly larger priming for the LH when abstract prime words were presented with high probability (Chiarello, et al., 1987); 2) RH facilitation effects (only) for categorical priming as compared to associative priming (Chiarello, et al., 1990; Chiarello & Richards, 1992); and 3) lack of semantic priming in the RH with short SOAs, but equivalent priming in both hemispheres with longer SOAs (Abernethy & Coney, 1993). It is important to note here that central versus lateralized presentation of prime words (with lateralized target stimuli) yields different outcomes in task performance. Central presentation results in equivalent priming effects for both hemispheres regardless of type of priming (categorical, associated, or combination), while lateralization of prime and target to the same VF results in priming effects that depend on the type of priming (Chiarello, 1990; Chiarello, Richards, & Pollock, 1992). However, Richards and Chiarello (1995) did find a RVFA for accurately pronouncing a target word preceded by a centrally-presented prime in a naming task. Perhaps different task demands for naming (e.g., speech production), as compared to lexical decision, can explain this discrepant finding.

Overall, there is a robust finding of hemispheric asymmetry in favor of the LH for performance on LDTs, according to behavioral measures such as accuracy and reaction time. Various task manipulations, including type of

priming, SOA, visual field of prime word, and word length of stimuli have illustrated that RH performance on lexical decision can be enhanced or hindered, as compared to LH performance. The investigation of how the RH processes language in all stages of lexical processing continues. With the help of neurophysiological procedures, these different stages of language processing can be examined more directly.

Event-Related Potentials

Despite the wealth of information that is gained through research using behavioral laterality approaches, only findings regarding the final output stage of language processing, as reflected by reaction times and accuracy measures, can be reported. Event-related potentials (ERPs), on the other hand, provide neurophysiological correlates for all stages of information processing, from stimulus input to response output. ERPs are derived by recording segments (or epochs) of electroencephalographic (EEG) data that are time-locked to a particular event. When such epochs are averaged across trials, task-irrelevant noise averages out and a waveform develops that can be interpreted as brain activity that occurs in preparation for or in response to discrete events. As such, ERPs are regarded as indications of certain sensory, motor, or psychological phenomena, such as specific stages in language processing. The various ERP components are usually named by using latency and valence of the peak amplitude. For example, the P300 typically occurs around 300 ms post-stimulus and has a positive polarity. This nomenclature can become confusing, however,

because a certain component may not occur at the designated latency. For example, the latency of a "P300" component increases with task difficulty, and can appear as late as 900 ms following stimulus onset. Consequently, this component is considered to measure the same process based on particular task demands, valence of the peak waveform, etc. In other words, just as reaction times can increase with increased task demands, the latency of certain ERP components are like-wise affected.

Compared to other neurophysiological measures of brain activity (e.g., PET, functional MRI), the temporal resolution for ERPs is excellent (approximately 1 ms), so the timing and sequencing of different stages of information processing can be systematically examined. However, the spatial resolution for ERPs is not as strong (8-11 mm) as other imaging techniques (functional MRI, PET), which can lead to questionable determination of localization of activity, particularly when dipole orientation is considered. The pyramidal cells that are believed to be the source of EEG recordings have been conceptualized by using dipoles, with axes perpendicular to the surface of the cortex. These dipoles are considered to be the origin of EEG, but can be oriented so that activity appears to be originating from a particular region, but is actually coming from another region (Cooper, Osselton, & Shaw, 1980). For example, an ERP may be "recorded" over the RH, but the generator of this brain activity may actually lie in the LH with the dipole orientation merely directed toward the right side. As an example, another ERP component, the N400, is

typically found to have a slightly larger amplitude over the RH than the LH, but this larger amplitude is believed to originate from the LH (Kutas & Van Petten, 1990, 1994). Despite these difficulties, attempts are being made to increase the localizing capabilities of EEG, but this requires an unusually large number of electrodes (60-120) which considerably increases "hook-up" time. Consequently, ERP data recorded with the standard number of electrodes is more appropriate when examining gross localization issues, rather than specialized areas of activity. Despite the spatial resolution limitations, EEG/ERP techniques are non-invasive, economical, and have excellent temporal resolution.

There are two main types of ERPs of interest to the researcher studying psychological processes. The first type of potentials is primarily controlled by the physical properties of an external event and is termed exogenous (or sensory), and includes ERPs such as the N1 (or N100) and P1 (or P100) which occur within the first 200 ms following presentation of a stimulus. The N100 reflects the initial orienting response and appears whenever an unexpected stimulus is processed, typically peaking over the vertex (center electrode Cz) of the scalp, and decreasing in amplitude with repeated stimulus presentation (Altenmuller, 1993). The N100 is also the earliest ERP that is modulated by selective attention (Hillyard, Hink, Schwent, & Picton, 1973). The N200 reflects several different types of processing related to stimulus evaluation, and can be broken down into three subcomponents: N2a ("mismatch negativity") occurs during pre-attentive (passive) discrimination; N2b reflects active discrimination, and the N2c indicates

the process of categorization (Altenmuller, 1993). As one can see, the N200 appears to exhibit properties that are related to more than mere sensory processing. As such, the N200 also shares some characteristics with the second type of ERPs discussed below.

The second type of ERP, the endogenous potentials, occurs later in time and is important to the study of language processing because it reflects "cognitive" processes such as decision making and memory updating. These potentials [e.g., P300, P3 or late positive component (LPC) and N400 or N4] can be elicited either by active processing as the participant engages in the task and responds, or when there is no external event (Coles, Gratton, & Fabiani, 1990). For instance, the P300 is frequently elicited by active decision-making, while the N400 can emerge when a person is reading for meaning, without having to fulfill immediate task demands such as decision-making. It is important to note that the exogenous/endogenous categorization is relative rather than absolute (e.g., the N2 can exhibit both exogenous and endogenous properties).

The P300 component commonly appears when a response is required. For example, in an oddball task there are two types of stimuli (high probability and low probability). When the infrequent stimulus is processed, a reliable, large P300 occurs (Donchin, 1981). The P300 has also been shown to be influenced by lexical factors. Halgren and Smith (1987) report a larger P300 amplitude for repeated words, believed to reflect ease of processing. Smith and Halgren (1987) found an increase in P300 amplitude to more common words in the

lexicon, as compared to less frequently used words. They also found no difference in P300 amplitude for pronounceable as compared to non-pronounceable non-words. Bentin, McCarthy, and Wood (1985) reported increased P300 latency for lexical decision of non-words as compared to words, with decreased P300 amplitudes as latency increased.

Kutas and Hillyard (1984) discovered an ERP component that has impacted the study of language processing. A large negativity around 400 ms (termed the N400) occurred when participants read a sentence with an anomalous word in the middle or at the end of the sentence, such as "He takes cream and sugar in his ATTENTION". The N400 effect is significantly reduced when the sentence has a congruent or expected ending: "He takes cream and sugar in his COFFEE". This variation in the N400 amplitude is considered an indication of semantic priming. Kutas and Hillyard (1984) chose the ending words for these sentences based on their "cloze probability" (hi/med/lo) (i.e., the proportion of people that used that word to complete the sentence). Sentences were classified by level of contextual constraint (hi/med/lo). A sentence with high contextual constraint leads to very predictable endings, while low contextual constraint leads to less expectancy about the ending of the sentence. They reported that the N400 amplitude is more sensitive to the cloze probability of the terminal word than to the degree of sentence contextual constraint, although the two are dependent upon each other. For example, higher cloze probability

attenuates the N400 effect, but the sentence must have high contextual constraint in order to have a high cloze probability for the terminal word.

Some basic characteristics of the N400 include an average peak latency of 350-400 ms with a 300-400 ms rise-fall duration, and a tendency to be slightly larger over the RH and parietal, posterior temporal and occipital regions (Kutas & Van Petten, 1994; Pritchard, Shappell, & Brandt, 1991). The N400 amplitude decreases with repeated presentations of a stimulus (Rugg & Nagy, 1987). While the N400 is produced by an incongruity in a sentence, this component is not simply a "mismatch detector". For example, the N400 is elicited by controlled (deeper) processing tasks (e.g., lexical decision), but not by automatic processing tasks that require only a shallow level of processing (e.g., physical matching tasks; use of degraded or masked stimuli in LDT) (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Holcomb, 1993). Results of Bentin, Kutas, and Hillyard (1993) could be interpreted in support of the N400 as an indicator of controlled processing. They found larger priming effects on the N400 in a task condition requiring deeper processing and more attention (memorize) than demands of their second task (counting).

Several researchers (Bentin, et al., 1993; Bentin, et al., 1985; Holcomb & Neville, 1990; Kutas & Hillyard, 1989) have reported that the N400 is affected by associative priming in various experimental paradigms across both auditory and visual modalities (e.g., lexical decision, memorizing, or counting non-words). For example, the N400 amplitude is significantly reduced when the prime and target

words are semantically related (e.g., KING-QUEEN) as compared to the unrelated prime condition (e.g., KING-NAIL). The N400 amplitude in tasks involving individual words is smaller than that elicited by tasks requiring reading of anomalous sentences because more effort is assumed for reading sentences than for reading words (Kutas & Van Petten, 1994).

So far, the N400 has been shown to be elicited by various experimental paradigms involving words. The N400 also occurs subsequent to exposure to orthographically legal (pronounceable) non-words, but not to orthographically illegal (non-pronounceable) non-words (see Kutas & Van Petten, 1994). These results suggest that the N400 reflects the early stage(s) of language processing such as word recognition, which offers a reason why non-pronounceable non-words are identified without eliciting an N400. Pronounceable non-words need further processing to determine that they are not words and do not fit in the context, resulting in the presence of N400 activity. These findings provide additional support for the idea that the N400 is involved in controlled, rather than automatic processing and does not simply represent a mismatch detector.

A late positive component (P300) is typically present whenever a response is required by a task, and can also be elicited by semantically congruous or incongruous endings (Friedman, Simson, Ritter & Rapin, 1975a, 1975b; Kutas & Hillyard, 1980; Polich, Vanasse & Donchin, 1981). Consequently, component overlap with the N400 is a common problem, making it difficult to determine whether the N400 is an actual measure of specific language

processing, or merely depends on latency shifts of this late positivity. Bentin, et al. (1985) addressed this problem by sorting ERPs according to lexical decision reaction times and then comparing semantic priming effects for each time block, which successfully reduced component overlap by controlling P300 latency jitter. Experimental design can also be used to address this problem by utilizing tasks that do not require actual decision-making proximal in time to the expected occurrence of the N400. For example, Kutas and Hillyard (1989) used semantic priming with a delayed decision response to postpone P300 onset, which can reduce N400 amplitude. Specifically, one second after the prime-target pair was viewed, the participant was presented with a letter and had to determine if it was present in either of the words of the prime-target pair. Deacon, Mehta, Tinsley and Nousak (1995) adapted Kutas and Hillyard's (1989) experimental paradigm by presenting a sequence of two words (either related or unrelated), followed by a "probe word". The participants were to decide if this third word was related to either of the first two words. Delaying the decision-making process was found to be successful in reducing component overlap between the P300 and the N400. The second experiment of this study was designed to address this issue of component overlap.

Event-Related Potentials and Laterality

Although behavioral data is useful, ERP responses to stimulus presentations in divided visual field studies can directly measure when, and to some extent where, processing is taking place. The N400 has been shown to be

larger over the LH than the RH for all the participants (n = 10) in Neville, Kutas, and Schmidt's (1982) study. This is a strong effect, but the task they used did not require processing of semantic anomaly that is commonly used to elicit the N400. Instead, the participants merely watched a word that was flashed and then wrote it down after a delay. Smith and Halgren (1987) found a similar LH lateralization of the N400 for both high and low frequency (non-repeated) words in a LDT. However, as mentioned earlier, the majority of findings report a larger N400 over the RH, as compared to the LH. This is surprising since LH dominance for language is well established, and the N400 has been shown to occur when stimuli are semantically incongruous. However, recall that dipole orientation can affect where an ERP is recorded, especially when making inferences about right and left hemispheric regions. Evidence for larger N400 activity over the RH may not accurately reflect the localization of the generator for the recorded cortical activity. Kutas, Hillyard, and Gazzaniga (1988) investigated this problem by using ERP data from split-brain patients. They presented sentences auditorily (binaurally), and the final word (congruous or incongruous sentence ending) was presented visually to either the LVF, RVF or BVFs for normals and split-brain patients. Hemispheric asymmetry of the N400 was found for split-brain patients when processing incongruous stimuli. For those split-brain patients with presumed LH language specialization, there was no N400 effect when incongruous information was lateralized to the LVF/RH. However, the N400 effect was present over both hemispheres when incongruous

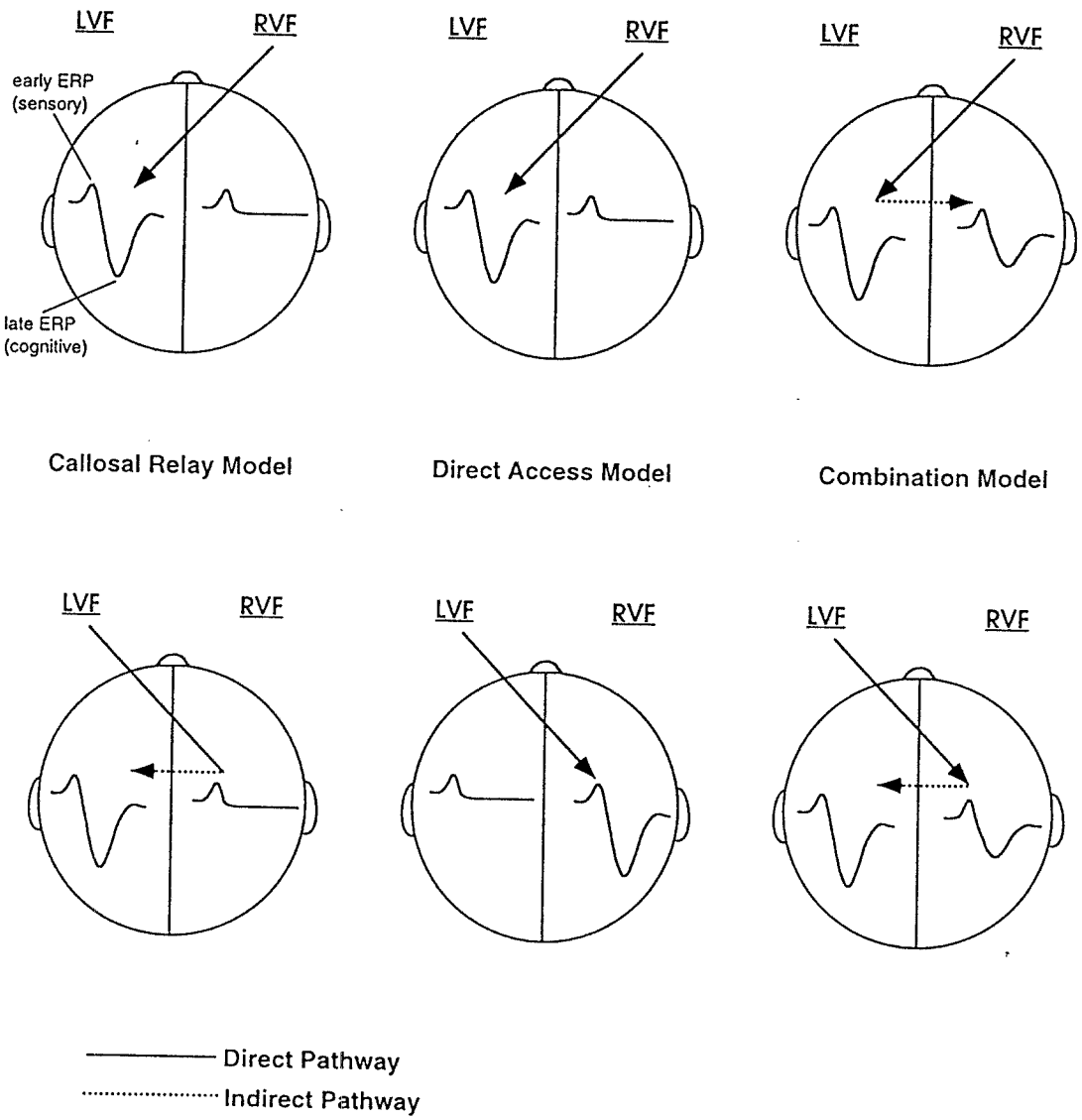
information was presented to the RVF/LH, which is surprising because there should not be interhemispheric transfer of information. This result could be explained by a deep midline generator of the N400 which depends on antecedent processing from the LH (see Smith & Halgren, 1987); or perhaps the dipole of the N400 generator is oriented toward the vertex, causing the N400 to appear over both hemispheres when it is actually generated over only the LH. For normals, there was no hemispheric difference for the N400 when incongruous endings were presented to either the LVF or the RVF. However, there was a non-significant trend for a greater N400 effect for RVF/LH anomalous stimulus presentations, similar to the findings from split-brain patients. They used a relatively small sample size ($\underline{n}$ = 8), which reduced their statistical power and may have resulted in missed laterality effects that would be expected for the N400. So, whether the generator of the N400 is lateralized to either the RH or the LH remains in question.

Rugg, et al. (1986) reviewed ERP research of hemispheric lateralization, and made predictions based on ERP and behavioral laterality findings. They discussed absolute specialization (i.e., callosal relay) and predicted behavioral asymmetries that are small and consistent across varying task difficulties based on this model. Relative specialization (i.e., direct access) predicts interactions between the magnitude of asymmetries and different task demands. These are the behavioral predictions, but what about predicted neurophysiological outcomes?

Event-related potentials can be used to determine the presence of lateralized processing during various stages when stimuli are presented to one VF. Rugg, et al. (1986) speculate about ERP patterns that should be found based on the models of absolute and relative hemispheric specialization. Early processing components (evoked before 200 ms after stimulus onset) are predicted to occur in both hemispheres, and should be slightly larger for direct (versus indirect) pathways. It is the later components that are of particular interest, however. According to callosal-relay, the specialized hemisphere should show a large late ERP via both direct (stimulus presented to contralateral VF) and indirect (stimulus presented to ipsilateral VF) pathways because the stimuli will not be processed by the non-specialized hemisphere; instead it will transfer to the specialized hemisphere (see Figure 2). (Recall, the visual field pathways are crossed.) If direct-access processing is taking place, then a large ERP will be seen over the hemisphere contralateral to the VF of stimulus presentation, regardless of hemispheric specialization, and it will follow the direct pathway. However, no ERP will be recorded over the opposite hemisphere (via the indirect pathway) because this model assumes there is no transfer of information. Rugg, et al. (1986) emphasize that early components reflect sensory processing that is assumed equivalent for both hemispheres, but later components are measures of central processing of the hemispheres, resulting in their presence only when the hemisphere is capable of performing the task. Most of the divided visual field ERP studies reviewed by Rugg, et al. (1986) used

Figure 2

Predicted ERP components for three models of language processing



fairly simple stimuli for elementary tasks. Recall, the processing dissociation pattern predicted by the direct-access model requires tasks of both high and low levels of complexity.

A thorough review of the literature revealed an absence of ERP studies of semantic priming with lateralized presentation of stimuli. Therefore, further investigation of how the hemispheres process language was pursued by conducting a series of three studies that address the various issues that have been discussed. The first experiment investigated hemispheric differences in an associated versus unassociated semantic priming paradigm, as well as hemispheric differences for processing of pronounceable and non-pronounceable non-words. The second experiment examined these same issues, but the task was changed to address component overlap. The third experiment used the same task as the second, but bilateral target presentation was used (rather than unilateral) to explore interhemispheric effects of associated and unassociated priming.

Predictions

In Experiment 1, semantic priming in both hemispheres was expected in the associated prime+target condition. If lateralized targets are indeed processed in a direct-access fashion, then hemispheric differences should be apparent for N400 amplitude. Based on data presented earlier, the N400 should be reduced in the prime condition (target is more "expected" in this condition), especially over the RH since the RH is more susceptible to priming effects. N400

amplitudes are expected to be larger to pronounceable than to non-pronounceable non-words. This difference should be larger over the LH since the LH is more susceptible to phonological effects.

In Experiment 2, there should be significantly reduced overlap between the late positive component (LPC which is also termed the P300) and N400 since a decision/response was delayed until well after the first target stimulus (T1) is presented. The N400 could then be examined more closely with this attenuation of the LPC, and results could be compared to Experiment 1.

In Experiment 3, bilateral presentation of identical stimuli should result in larger LPC amplitudes if interhemispheric cooperation occurs. Furthermore, an interhemispheric cooperation model predicts a larger N400 effect (unassociated - associated) for bilateral redundant stimuli than when associated and unassociated targets appear in opposite visual fields. A direct access model is supported if there are hemispheric asymmetries for the N400 effect when associated and unassociated targets are in opposite VFs. Specifically, the VF with the associated prime should have a smaller (or absent) N400 than the VF with the unassociated prime.

CHAPTER II

METHOD

Participants

A total of 49 right-handed, Psychology undergraduate students participated in the study (Experiment 1: 11 females and 4 males; Experiment 2: 10 females and 6 males; Experiment 3: 14 females and 4 males). The presence of familial sinistrality (left-handedness) was screened prior to participation in the study. Those participants with familial sinistrality were then excluded from the study because organization of language in the brain has been shown to be affected by this variable. Other selection criteria (gathered by self report) include English as the native language, normal/corrected to normal vision, and no history of reading problems or neurological disorders.

Stimuli

The stimuli consisted of 80 (Experiments 1 and 2) or 120 (Experiment 3) associated word pairs (e.g., ARM-LEG), an equivalent number of unassociated word pairs (e.g., BOOK-SNOW), 80 (Experiments 1 and 2) pronounceable non-words (e.g., BLEP), and 80 (Experiments 1 and 2) non-pronounceable non-words (e.g., CKLB). All words were concrete nouns of 3-6 letters. Associated prime-target pairs were selected from lists of free association word norms generated by McCann and Clarke (submitted for publication, see Table 1, Appendix) and by

Shapiro and Palermo (1968). Unassociated prime-target pairs consisted of an entirely new set of words matched to the associated prime-target pairs for word length, concreteness, and frequency. The non-words were also 3-6 letters in length with pronounceable non-words containing vowels and consonants in a legal orthographic manner, and non-pronounceable non-words consisting of consonants only.

A Macintosh Quadra was used for stimulus delivery on a 16" color monitor positioned approximately 3-3.5' in front of the participant. All stimuli were displayed horizontally in uppercase letters, except T2 stimuli which were presented in lowercase letters, and subtended a visual angle of 1.5-3.0 °. For lateralized stimuli, the inner edge of each stimulus was 1.5 ° from the vertical meridian. The software program MacProbe (Hunt, 1994) was used for stimulus presentation, behavioral data collection, and to send out marker signals that interfaced with EEG collection.

Experimental Procedure

Experiment 1. Experiment 1 is a lateralized, primed lexical decision task consisting of eight different conditions, 40 trials each, for a total of 320 trials. In all trials, participants were required to respond "word" or "non-word" by pressing one of two mouse buttons as quickly and accurately as possible to a lateralized letter string (target) that was preceded by a centrally-presented prime word. Conditions 1 and 2 included 40 trials of prime+associated target pairs for the LVF and RVF, respectively; conditions 3 and 4 included 40 trials of

prime+unassociated target pairs for each visual field; conditions 5 and 6 consisted of 40 trials of prime+pronounceable non-word pairs for each visual field; and conditions 7 and 8 consisted of 40 trials of prime+non-pronounceable non-word pairs for each visual field. All conditions were intermixed by using a digram balance Latin square matrix model and were presented in random order. Response hand was manipulated by having each participant change response hands after completing 160 of the 320 trials. Initial response hand was counterbalanced across subjects. The index finger was used to depress the left mouse button for a response of "word", and the middle finger was used to depress the right mouse button to indicate a response of "non-word", regardless of the hand being used.

After initial screening procedures with questionnaire data, standardized experimenter presentation of the task instructions were given, in addition to a series of practice trials, where feedback was offered regarding accuracy (via computer) and eye movement (via experimenter). For each trial there was simultaneous presentation of a 50 ms, 1500 Hz alerting tone and a central fixation marker (+). After a variable delay (500-1000 ms, $\underline{M}$ = 750 ms), the prime word was displayed centrally for 100 ms, 1° above the fixation marker. Following an 800 ms stimulus-onset asynchrony, (SOA) (from prime onset), the target string was shown for 120 ms randomly to the left or right visual field, 1° above and 1.5° to the left or right of the fixation marker. After a 1500 ms period (from target onset) to make a "word" or "non-word" response, the fixation marker

disappeared from the screen, leaving the participant time to blink (as previously instructed during the practice trials) before initiation of the next trial (i.e., to reduce EEG artifacts during recorded epochs). The following trial began subsequent to another 1500 ms period.

Experiment 2. Because a decision/response always produces an LPC which can overlap and obscure an N400 component, Experiment 2 was designed to delay decisions/responses until well after the prime-target pair has been presented. In order to accomplish this, Experiment 2 utilized a delayed matching task with the same eight conditions described for Experiment 1. Following each prime-target pair, there was a second target (T2) that either matched or differed from the first target (T1). Participants were to decide whether T2 was a match or mismatch of T1. (T2 stimuli never matched the prime word for all conditions.) The remaining procedure was similar to Experiment 1, except the index finger was used to depress the left mouse button for a "match" and the middle finger was used to depress the right mouse button for "no match", regardless of hand being used.

The presentation sequence was the same as Experiment 1, except that 800 ms following lateralized presentation of T1, T2 was centrally presented for 120 ms, 1° above the fixation marker. The participant had 1500 ms to make a "match" or "no match" decision before the fixation marker disappeared. The next trial commenced after another 1500 ms.

Experiment 3. Experiment 3 was also a delayed matching task with central presentation of the prime, but T1 was presented bilaterally (i.e., to LVF and RVF simultaneously), while T2 remained centrally presented. There were 5 different conditions as follows: condition 1 - target words (T1 in both visual fields) were identical and associated to the prime (IA); condition 2 - T1 words were identical and unassociated to the prime (IU); condition 3 - T1 (LVF) was associated to the prime and T1 (RVF) was unassociated to the prime (LARU); condition 4 - reverse of condition 3 (LURA); and condition 5 - both T1 words were different from one another and unassociated to the prime (DU).

The remaining procedure was identical to that of Experiment 2, with the exception of bilateral presentation of T1 words and the absence of non-word stimuli. T2 words were centrally presented 1° above the fixation marker for all conditions. If either the LVF or RVF T1 stimulus matched T2, this was considered a "match" trial, otherwise the participant was instructed to hit the "no match" button on the mouse (e.g., neither LVF nor RVF T1 matches T2).

Recording Procedure

Participants were seated in a comfortable chair located in a sound-attenuated room, and an electrocap (Electro-Cap International, Inc., Eaton, OH) containing 21 tin electrodes was fitted to the scalp. These electrodes include the 20 standard International 10-20 system locations (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, 01, 02) plus a ground connection at Fpz. Two additional electrodes were attached at the outer canthus of each eye for

monitoring horizonal eye movements (bipolar derivation), while Fp2 was used for monitoring vertical eye movements and blinks. The site of reference was the nose tip. A linked earlobe reference was not used since unequal impedances of the left and right earlobes can produce artifactual hemispheric differences in ERPs (Alexander, et al., 1995; Kutas & Van Petten, 1994). All impedances were maintained at less than or equal to 3 kOhm. A Model 200 EEG electrode impedance meter (GDR Research, Lewisville, TX) was used to facilitate measurement of impedances, reducing the amount of "hook-up" time. The EEG data was collected using a BiologicBrain Atlas III (Biologic systems Corp., Mundelein, IL) electroencephalogram. The software program ASYST (Keithley Metra Byte, Taunton, MA) was used to collect, average, and analyze the data. The EEG signals were amplified by 15,000 times and collected at 333 Hz with 12 bit resolution and a low frequency filter setting of 0.1 Hz and high frequency filter setting of 30 Hz. Epochs of approximately 1 s duration were collected with the first 100 ms prior to target presentation used as a baseline.

Data Scoring and Statistical Design

Off-line averaging of the EEG epochs and removal of trials with artifacts (e.g. eye blinks or eye movements) were conducted initially. Amplitudes (uV) for ERPs (e.g. N90, LPC, N400) were then calculated relative to the baseline measure for each task condition. In addition, behavioral measures (mean reaction time and accuracy of response) were calculated for each trial.

Mean reaction times and error rates were analyzed using repeated measures analysis of variance (ANOVA) for the different tasks. Amplitude measures for each ERP component were also analyzed using ANOVAs with repeated measures for each experiment. In order to study hemispheric effects, separate ANOVAs were performed for midline and lateral electrode sites. Specific statistical procedures are outlined prior to each experiment in Chapter III.

CHAPTER III

RESULTS

General Results Procedures

Behavioral data. For each of the experiments, mean reaction times and error rates were analyzed using repeated measures analysis of variance (ANOVA), with a .05 Type I error rate.

ERP data. Mean amplitudes for specific time windows were measured for each ERP component of interest. Separate analyses were conducted for midline and lateral sites to examine hemispheric effects more closely. Univariate ANOVAs with repeated measures were used to analyze each ERP component. A .01 significance level was used for each main effect and interaction in an attempt to control for Type I error rates due to multiple tests, without unduly increasing the probability of Type II errors. Occasionally, descriptive statistics were presented for latency effects.

EXPERIMENT 1 - LATERALIZED PRIMED LEXICAL DECISION

Behavioral Data

Reaction time (RT) and accuracy scores were each analyzed with three separate repeated measures ANOVAs. The first analysis focused on the effects of word versus non-word target stimuli. The subsequent analyses examined word and non-word targets separately. In this manner, word targets could be

examined for effects of associated priming, and non-word targets could be examined for effects of pronounceability.

Analyses of All Trials

The analyses involving all trials used within-subjects factors of target and visual field (VF) resulting in a 2 (word, non-word) x 2 (left, right) ANOVA. As expected, word targets elicited a faster response (M = 808 ms) than non-word targets (M = 887 ms), [$F(1, 14) = 29.68$, $p = .0001$]. Responses to word targets were also more accurate (88.2% correct vs. 82.5% correct), [$F(1, 14) = 9.84$, $p = .007$]. Participants responded to right visual field (RVF) targets more quickly (826 ms vs. 869 ms), [$F(1, 14) = 60.76$, $p < .0001$], and more accurately (89.5% correct vs. 81.3% correct), [$F(1, 14) = 33.55$, $p < .0001$], than left visual field (LVF) targets. There were no significant interaction effects between target type and visual field of target presentation for both RT and accuracy.

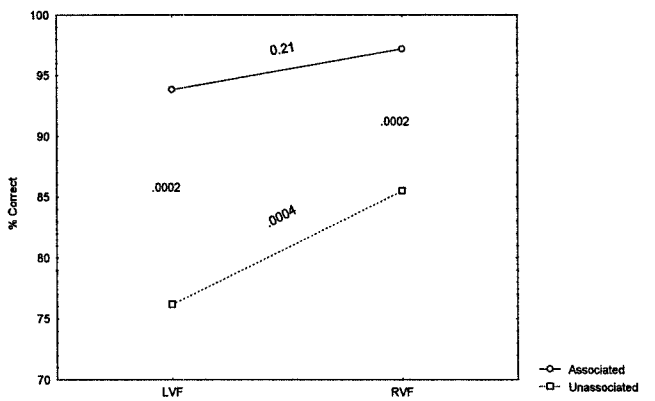
Analyses of Word Targets Only

To examine the nested factor (word target) more closely, 2 x 2 ANOVAs were performed for word target trials by using within-subjects factors of prime word type (associated, unassociated) and VF (left, right). Results of these analyses yielded an advantage of associated prime-target pairs over unassociated prime-target pairs for both reaction time (M = 758 ms vs. M = 870 ms), [$F(1, 14) = 48.26$, $p < .0001$] and accuracy (95.5% correct vs. 80.8% correct), [$F(1, 14) = 34.46$, $p < .0001$]. There was also a RVF advantage for both reaction time (M = 793 ms vs. M = 834 ms), [$F(1, 14) = 23.12$, $p = .0003$] and

accuracy (91.3% correct vs. 85.0% correct), [$F(1, 14) = 15.54$, $p = .0015$]. Although there was no significant interaction effect between prime word type and VF for reaction time, this interaction was significant for accuracy scores [$F(1, 14) = 6.97$, $p = .019$]. Tukey HSD post hoc analyses revealed a significant VF difference for only unassociated prime-target pairs (RVF advantage, see Figure 3). It may be the case that associative priming lessens the VF difference by aiding right hemisphere (RH) processing, while left hemisphere (LH) performance approaches ceiling levels. Difference scores were calculated by subtracting mean accuracies for unassociated prime-target trials from associated prime-target trials to further examine priming effects. Targets presented to the RVF produced an 11.67% priming effect, while those presented to the LVF yielded a 17.66% priming effect. These scores further support the notion of semantic priming enhancing RH performance more than LH performance because accuracy improved more with associative priming for the RH (LVF) than the LH (RVF).

Figure 3

Interaction between association and visual field for accuracy scores



Analyses of Non-word Targets Only

Analyses for non-word target trials were conducted by performing 2 x 2 ANOVAs using within-subjects factors of non-word target type (pronounceable, non-pronounceable) and VF (left, right). These results revealed an advantage of non-pronounceable target trials over pronounceable target trials for both reaction time (M = 846 ms vs. M = 937 ms), [$F(1, 14) = 70.68$, $p < .0001$] and accuracy (89.7% correct vs. 75.48% correct), [$F(1, 14) = 134.05$, $p < .0001$]. There was also a RVF advantage for both reaction time (M = 868 ms vs. M = 915 ms), [$F(1, 14) = 60.45$, $p < .0001$] and accuracy (87.6% correct vs. 77.5% correct), [$F(1, 14) = 25.08$, $p = .0002$]. There were no significant interaction effects between non-word type and VF for reaction time and accuracy.

In sum, there was a consistent RVF advantage for both word and non-word targets. Within word type, associated prime-target pairs resulted in faster and more accurate responses. For non-words, non-pronounceable targets also

resulted in faster and more accurate responses. Although all trials and non-word target analyses yielded no significant interaction effects between VF and prime-target type, word target trials did show such an effect. Specifically, there was a significant interaction between prime-target type and VF for accuracy scores, where unassociated prime-target pairs showed a RVF advantage. In this case it may be more difficult for the RH to accurately process this type of stimuli, resulting in a LH (RVF) advantage. For associated prime-target pairs, ceiling levels may have prevented any hemispheric differences from emerging. Perhaps this interaction between VF and prime word is absent for RT scores because the LH is not limited by a ceiling score.

ERP Data

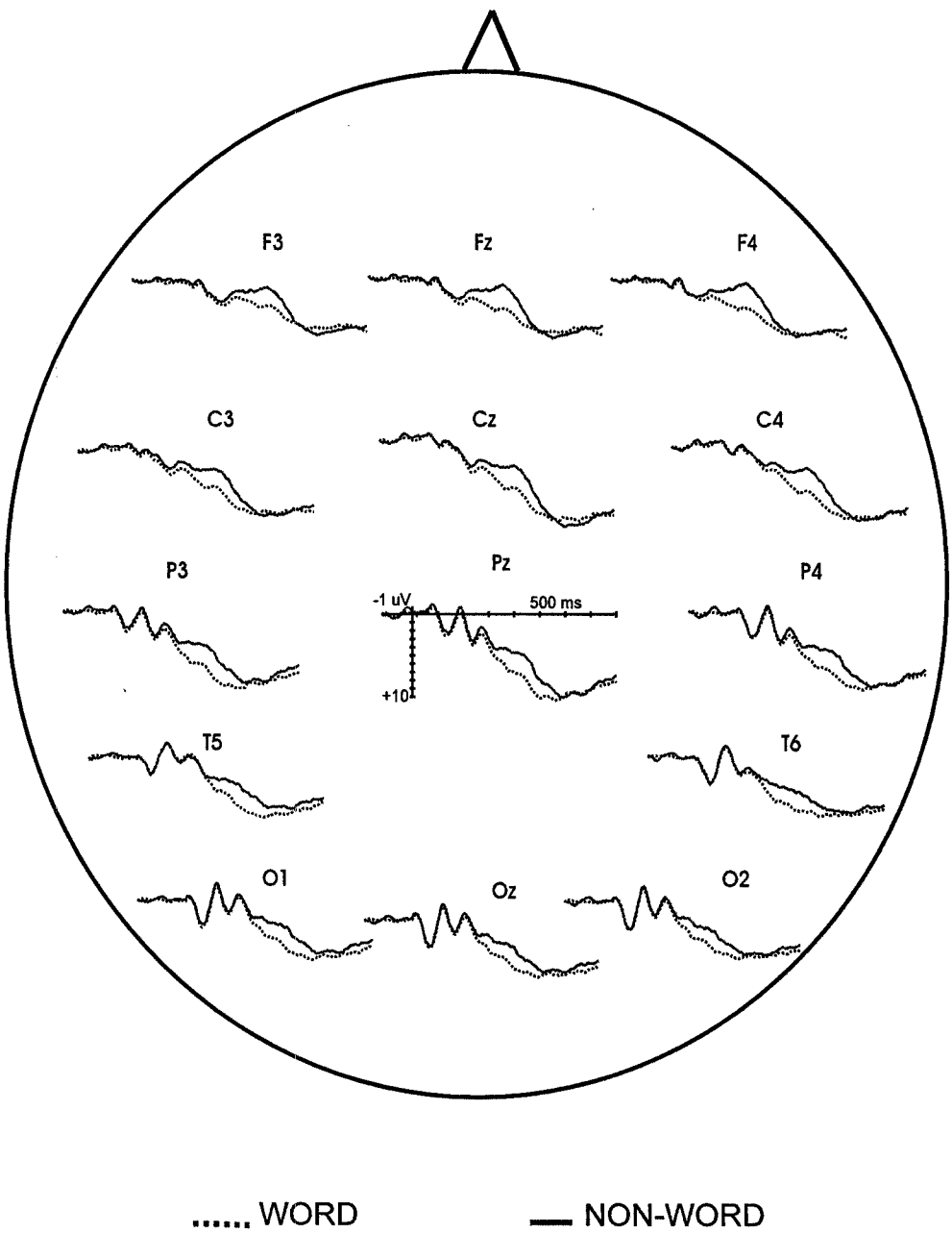
The ERP components were identified by peak latency, polarity, and topography (anterior, posterior). Figure 4 illustrates typical ERPs found from this experiment. Mean amplitudes were determined for each component within specified latency windows. Subsequently, three ERPs emerged for all electrode sites, including an N90 (70-110 ms latency window), N400 (300-500 ms), and a late positivity component (LPC at 500-650 ms). Within a 100-300 ms latency window waveforms differed for anterior and posterior sites, necessitating separate analyses for these ERPs. For anterior sites (F, C) an N140 (100-180 ms) and P240 (180-300 ms) were examined. Posterior sites (T, P, O) revealed a P130/N190 complex (110-210 ms) and a P230/N290 complex (210-300 ms). The data will be presented separately for all trials, word target trials only, and

non-word target trials only, as described in the behavioral data results section. Each ERP component will be discussed separately by reviewing results from analyses of midline sites (Fz, Cz, Pz, Oz) and then of lateral sites (F3, F4, C3, C4, P3, P4, T5, T6, O1, O2). In general, significant effects will be reported for amplitude differences of approximately 1uV or more. The Tukey HSD procedure was performed for all pair-wise post hoc analyses, with a family-wise Type I error rate of .05. The smallest p value set by Statistica software for Tukey pairwise comparisons was .000168, resulting in a reported p value of .0002 for the most significant effects for some interactions. Also, note that amplitudes for waves of negative polarity are larger when positive numerical values (uV) are smaller or negative numerical values are larger.

Figures of significant findings will be presented for the highest order interactions, and it should be assumed that all lower order effects for a component will be represented by these figures unless otherwise stated.

Figure 4

ERPs across all sites for word versus non-word stimuli in Experiment 1



N90 (70-110 ms): Midline Sites

Analyses of all trials. A 2(word, non-word) x 2 (nested variable of association and pronounceability) x 2 (left, right VF) x 4 (Fz, Cz, Pz, Oz) ANOVA yielded no significant results.

Analyses of word targets only. A 2 (associated, unassociated) x 2 (VF) X 4 (site) ANOVA yielded no significant results.

Analyses of non-word targets only. A 2 (pronounceable, non-pronounceable) x 2 (VF) x 4 (site) ANOVA yielded no significant results.

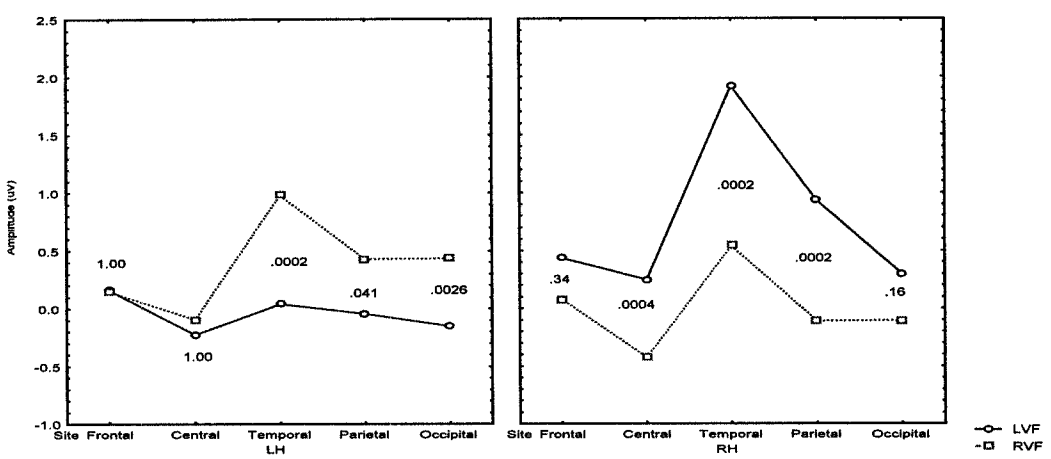
N90 (70-110 ms): Lateral Sites

Analyses of All Trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (F, C, T, P, O sites) x 2 (left, right hemisphere) ANOVA yielded a significant effect of site [$F(4, 56) = 3.52$, $p = .013$]. Post hoc analyses revealed only one significant difference between central and temporal sites, with central sites being more negative ($M = -0.12$ uV) than temporal sites ($M = .87$ uV). There were also two significant two-way interaction effects, VF x hemisphere [$F(1, 14) = 34.56$, $p < .0001$] and site x hemisphere [$F(4, 56) = 5.55$, $p = .0008$]. These interactions are contained within the significant higher order interaction of VF x site x hemisphere [$F(4, 56) = 18.41$, $p < .0001$] as shown in Figure 5, so they will not be analyzed further. Post hoc analyses for this interaction revealed significant VF differences over the LH, where temporal, parietal, and occipital sites produced a smaller amplitude for RVF (direct) than for LVF (indirect) presentations. Similarly, central, temporal, and parietal sites produced a smaller amplitude for LVF

presentation (direct pathway) for RH sites. These results are surprising, since the direct pathway should produce a larger mean amplitude as they reflect early, visual processing that is strongly affected by VF presentation. This paradoxical finding may be due to dipole orientation. However, these interpretations are inconclusive since the latency of wave onset is consistent with predicted findings, where the direct pathway produces an earlier peak amplitude.

Figure 5

Interaction of visual field x site x hemisphere for N90 amplitudes at lateral sites for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) X 5 (site) x 2 (hemisphere) ANOVA yielded results consistent with the above analyses of all trials. There were significant interactions for VF x hemisphere [$F(1, 14) = 15.67$, $p = .0014$], and site x hemisphere [$F(4, 56) = 4.02$, $p = .0061$] which are both contained within the higher order interaction for VF x site x hemisphere [$F(4, 56)$

= 14.29, $p < .0001$], similar to that described above (see Figure 5). Post hoc analyses showed significantly smaller amplitudes for temporal, parietal, and occipital sites over the LH receiving RVF stimuli (direct pathway), and temporal and parietal sites over the RH showing the opposite effect (also direct pathway). Once again, these results are paradoxical as explained above.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA also yielded findings consistent with the above analyses for all trials, with significant interactions for VF x hemisphere [$F(1, 14) = 70.75$, $p < .0001$] and site x hemisphere [$F(4, 56) = 6.83$, $p = .0002$] which are both contained within the interaction for VF x site x hemisphere [$F(4, 56) = 16.62$, $p < .0001$], which is similar to the same interaction discussed for all trials (see Figure 5). Over the LH, only temporal sites showed a significantly smaller amplitude for RVF (direct pathway) stimuli, while there were significantly smaller amplitudes for LVF (direct pathway) stimuli for all lateral sites over the RH. These paradoxical findings are also consistent with those discussed previously. There was an additional interaction of pronounceability x VF x site [$F(4, 56) = 5.12$, $p = .0014$], but this is likely a spurious finding since the differentiation between pronounceable and non-pronounceable non-words is not likely to occur so early in visual processing.

Overall, there were no significant effects for the N90 along midline sites, while lateral sites showed a consistent paradoxical effect where ipsilateral (indirect) VF presentation of stimuli resulted in larger N90 amplitudes over both

hemispheres. In addition, this component had larger negative amplitudes over posterior sites, which is consistent with predictions based upon early visual processing during this latency window.

N140 (100-180 ms): Anterior Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 2 (site) ANOVA yielded no significant effects.

Analyses of word targets only. A 2 (association) x 2 (VF) x 2 (site) ANOVA revealed no significant main or interaction effects.

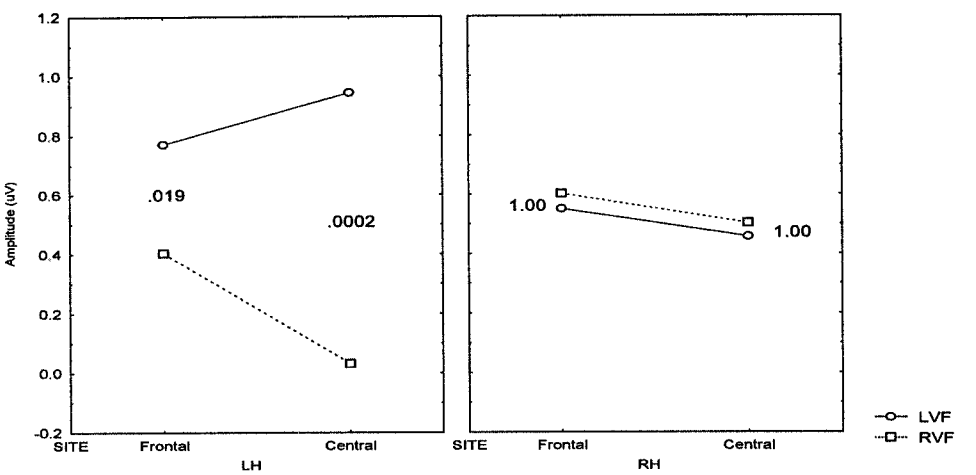
Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 2 (site) ANOVA yielded no significant main or interaction effects.

N140 (100-180 ms): Anterior Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 2 (site) x 2 (hemisphere) ANOVA revealed a significant interaction of VF x hemisphere [$F(1, 14) = 13.65$, $p = .0024$], which is contained within the interaction for VF x site x hemisphere [$F(1, 14) = 8.96$, $p = .0097$]. Post hoc analyses revealed a VF difference over the central LH region, where RVF presentation resulted in a more negative amplitude than LVF presentation, while frontal LH site showed a similar pattern to a lesser degree, and RH sites showed no VF difference (see Figure 6).

Figure 6

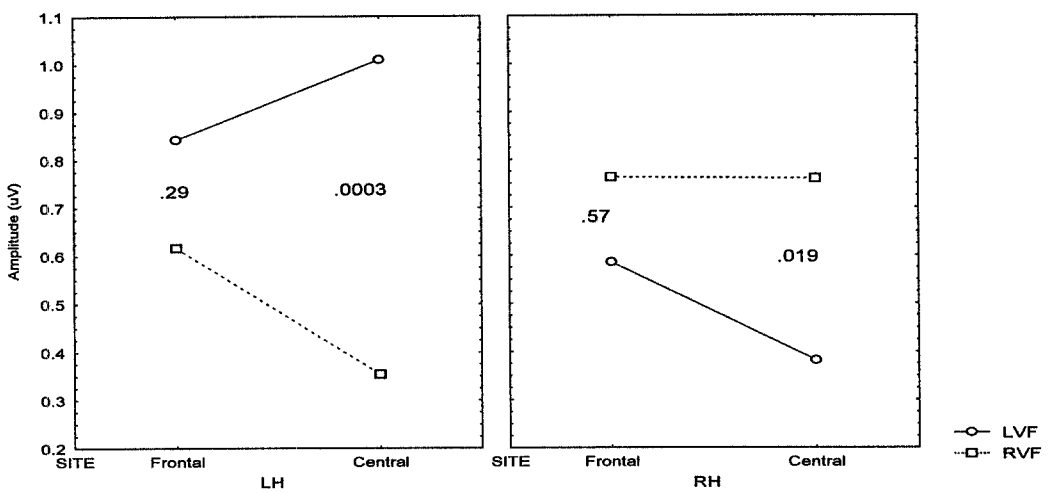
Interaction of visual field x site x hemisphere for N140 amplitudes at anterior lateral sites for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) x 2 (site) x 2 (hemisphere) ANOVA yielded a significant interaction effect for VF x site x hemisphere [$F(1, 14) = 11.55$, $p = .0043$]. Post hoc analyses revealed VF effects across both hemispheres. Although there were no significant VF differences for both frontal and RH central sites, RVF (direct) presentation for the LH central site evoked a significantly larger negative amplitude (see Figure 7).

Figure 7

Interaction of visual field x site x hemisphere for N140 amplitudes at anterior lateral sites for word only trials



Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 2 (site) x 2 (hemisphere) ANOVA revealed a significant interaction effect for VF x hemisphere [$F(1, 14) = 12.60$, $p = .0032$]. Post hoc tests showed a significant VF difference over the LH, where RVF (direct) presentation resulted in larger N140 amplitudes, while there were no VF differences over the RH. No other significant effects were found.

Overall, there were no significant effects for midline sites. Lateral sites showed VF effects over the LH where RVF (direct) presentation resulted in larger negative amplitudes than LVF presentation. There were no VF effects over the RH for non-word targets, while word targets showed the same VF difference of larger N140 amplitudes for LVF (direct) presentation of stimuli. These findings

are consistent with predictions that there should be larger amplitudes in response to stimuli presented via the direct, rather than indirect, pathway.

P130/N190 (110-210 ms): Posterior Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 2 (site) ANOVA yielded no significant main or interaction effects.

Analyses of word targets only. A 2 (association) x 2 (VF) x 2 (site) ANOVA yielded no significant main or interaction effects.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 2 (site) ANOVA also yielded no significant main or interaction effects.

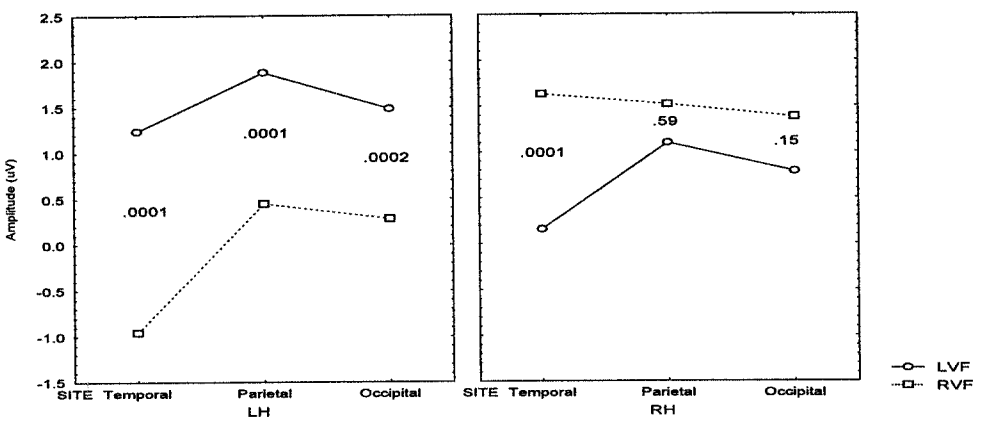
Similar to the midline analyses of the N90, analyses for the anterior N140 and posterior P130/N190 for midline sites yielded no significant results, emphasizing the lack of laterality (VF) effects for midline recordings.

P130/N190 (110-210 ms): Posterior Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 3 (site) x 2 (hemisphere) ANOVA revealed a significant interaction between VF and hemisphere [$F(1, 14) = 24.79$, $p = .0002$], which is contained within the higher order interaction of VF x site x hemisphere [$F(2, 28) = 15.00$, $p < .0001$]. Post hoc analyses revealed a consistent VF difference across T, P, and O sites over the LH where stimulus presentation via the direct pathway (RVF) resulted in larger negative amplitudes (see Figure 8). Over the RH a similar trend emerged, where the direct pathway (LVF) also resulted in larger negative amplitudes, but this VF difference was significant only for the temporal site.

Figure 8

Interaction of visual field x site x hemisphere for P130/N190 amplitudes at posterior lateral sites for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) x 3 (site) x 2 (hemisphere) ANOVA also revealed a significant main effect of site [$F(2, 28) = 6.04$, $p = .0066$], where amplitudes at temporal sites ($M = 0.54$) were significantly more negative than parietal sites ($M = 1.39$ uV, $p = .0054$) but not occipital sites ($M = 1.10$ uV). There was a significant interaction of association x site [$F(2, 28) = 5.56$, $p = .0093$], but the amplitude differences between associated and unassociated conditions were all less than 0.20 uV. Additionally, it is not likely that these findings reflect true cognitive differences attributed to association, since processing is likely to be more sensory than cognitive for this early component. There was also a significant VF x hemisphere interaction [$F(1, 14) = 26.04$, $p = .0002$], which is contained within the VF x site X hemisphere interaction [$F(2, 28) = 14.26$, $p = .0001$]. Post hoc analyses revealed a pattern

consistent with the analyses of all trials where VF presentation for the direct pathway shows more negative amplitudes across all sites (see Figure 8).

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 3 (site) x 2 (hemisphere) ANOVA revealed significant interaction effects for VF x hemisphere [$F(1, 14) = 21.11$, $p = .0004$] and VF x site x hemisphere [$F(2, 28) = 13.83$, $p < .0001$] which are also similar to the pattern discussed for all trials where presentation of stimuli via the direct pathway resulted in larger negative amplitudes (see Figure 8). Overall amplitudes for LVF presentation were more positive over the LH (indirect pathway) and more negative over the RH (direct pathway). Overall amplitudes for RVF presentation were negative over the LH (direct pathway) and more positive over the RH (indirect pathway). Additionally, hemispheric differences seem greater for RVF presentation (see Figure 8).

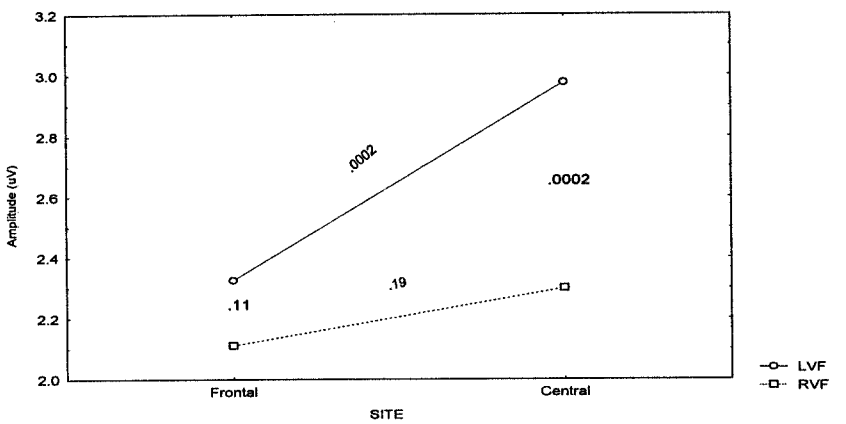
In sum, there were no significant effects for midline sites. For lateral sites, presentation of stimuli via the direct pathway again resulted in larger negative amplitudes over both hemispheres across most sites, while ipsilateral (indirect) presentation of stimuli resulted in larger positive amplitudes.

P240 (180-300 ms): Anterior Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 2 (site) ANOVA revealed a significant interaction between VF and site [$F(1, 14) = 14.03$, $p = .0022$]. Post hoc tests showed no significant VF differences for Fz, but at Cz, P240 amplitudes were larger for LVF than RVF presentation (see Figure 9). No other significant effects were found.

Figure 9

Interaction between visual field and site for P240 amplitudes at anterior midline sites for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) x 2 (site) ANOVA revealed no significant main or interaction effects.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 2 (site) ANOVA yielded no significant main or interaction effects.

P240 (180-300 ms): Anterior Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 2 (site) x 2 (hemisphere) ANOVA revealed a significant interaction of VF x site [$F(1, 14) = 12.64$, $p = .0032$], similar to that found in the midline analyses (see Figure 9). Post hoc tests revealed larger P240 amplitudes over central sites for LVF than RVF presentation, while frontal sites showed no VF difference. No other significant effects were found.

Analyses of word targets only. A 2 (association) x 2 (VF) x 2 (site) x 2 (hemisphere) ANOVA yielded no significant results.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 2 (site) x 2 (hemisphere) ANOVA revealed findings consistent with the all trials analysis, where a significant interaction effect of VF x site was found [$F(1, 14) = 13.54$, $p = .0025$]. Post hoc tests again revealed the same pattern discussed for all trials (see Figure 9). No other significant effects were found.

Overall, P240 amplitudes were significantly larger over central sites for LVF than RVF target presentations, while no VF differences were found over frontal sites.

P230/N290 (210-300 ms): Posterior Midline Sites

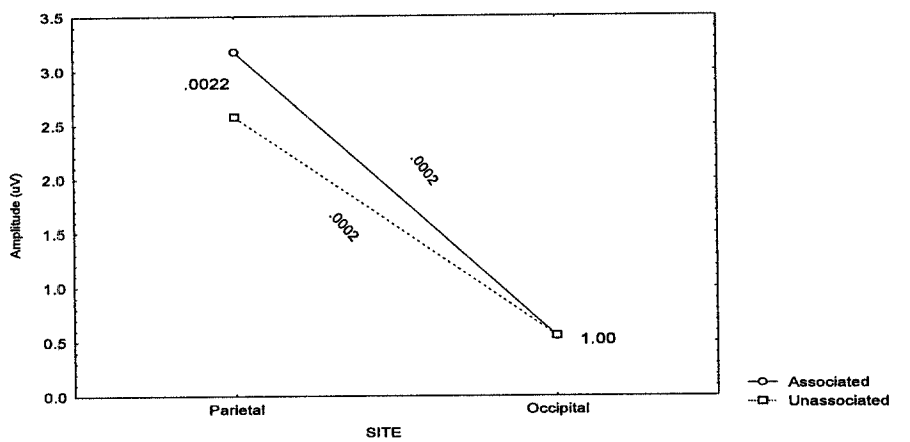
Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 2 (site) ANOVA revealed a significant main effect of site [$F(1, 14) = 17.70$, $p = .0009$]. Post hoc tests revealed a more positive amplitude for Pz ($M = 2.57$ uV) than for Oz ($M = 0.40$ uV). No other significant effects were found.

Analyses of word targets only. A 2 (association) x 2 (VF) x 2 (site) ANOVA also revealed a significant main effect of site [$F(1, 14) = 21.07$, $p = .0004$] with a larger positive amplitudes at Pz ($M = 2.87$ uV) than at Oz ($M = 0.55$ uV). A significant interaction occurred for association x site [$F(1, 14) = 10.68$, $p = .0056$], where amplitudes at Pz were more positive for associated than for unassociated prime-target pairs and amplitudes at Oz did not differ by association (see Figure 10). These findings suggest that some facilitation due to associated priming is

occurring over the parietal site, but not over the occipital site, and presumably reflects cognitive versus sensory stages of processing, respectively.

Figure 10

Interaction between association and site for P230/N290 amplitudes at posterior midline sites for word only trials



Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 2 (site) ANOVA revealed consistent findings, where a significant main effect of site was found [$F(1, 14) = 14.34$, $p = .0020$], and the amplitude at Pz was significantly more positive ($M = 2.28$ uV) than at Oz ($M = 0.26$ uV).

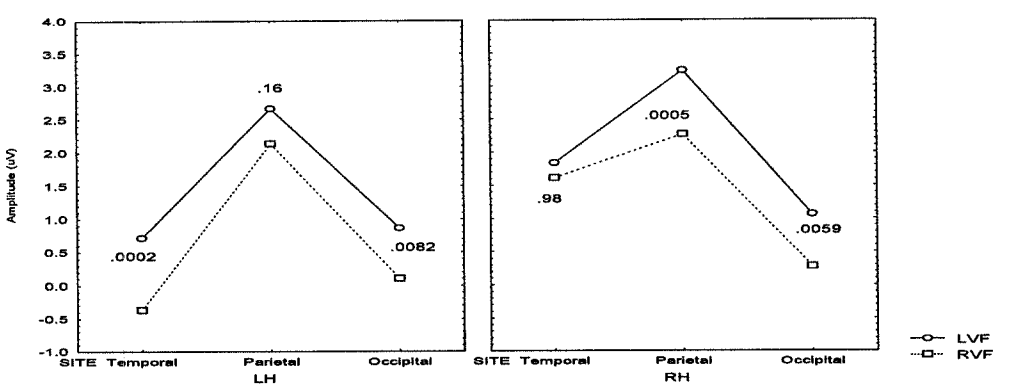
P230/N290 (210-300 ms): Posterior Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 3 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of site [$F(2, 28) = 14.26$, $p = .0001$], where post hoc tests revealed a significantly more positive amplitude for parietal sites ($M = 2.57$ uV) as compared to temporal ($M = 0.95$ uV)

and occipital sites (M = 0.58 uV) which did not significantly differ from one another. There was a significant interaction effect of site x hemisphere [F(2, 28) = 25.03, p < .0001], which is contained within the significant interaction of VF x site x hemisphere [F(2, 28) = 7.05, p = .0033]. Post hoc analyses revealed a significant VF difference for temporal and occipital sites over the LH, and for parietal and occipital sites over the RH, where LVF presentation always produced a more positive amplitude, regardless of hemisphere (see Figure 11). Left VF presentation, regardless of whether it was the direct or indirect pathway, always produced the larger positivity.

Figure 11

Interaction for VF x site x hemisphere for P230/N290 amplitudes at posterior lateral sites for all trials

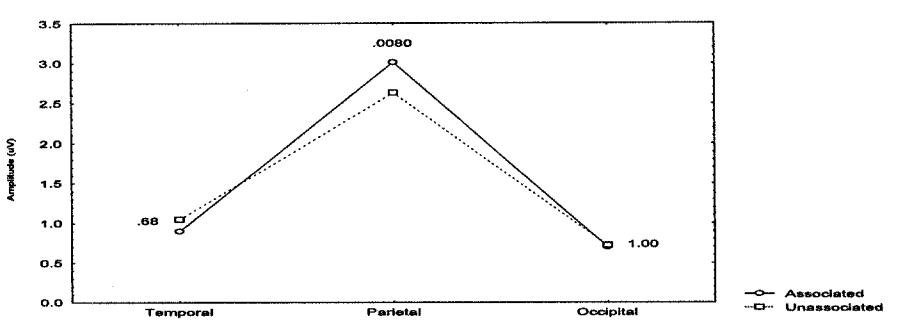


Analyses of word targets only. A 2 (association) x 2 (VF) x 3 (site) x 2 (hemisphere) ANOVA also revealed a significant main effect of site [F(2, 28) = 15.62, p < .0001], with the identical pattern discussed above for the analyses of

all trials. There was a significant interaction of association x site [F(2, 28) = 7.67, p = .0022], where parietal sites show a significantly more positive amplitude for associated word pairs, as compared to unassociated word pairs (p = .0080), apparently reflecting ease of processing, rather than only sensory differences (see Figure 12). There was also a significant site x hemisphere interaction [F(2, 28) = 15.71, p < .0001], which is contained within the VF x site X hemisphere interaction [F(2, 28) = 5.95, p = .0070] that follows the same trend as that discussed for all trials (see Figure 11). Post hoc analyses revealed a VF difference for T5 (LH), with LVF (indirect) presentations resulting in a more positive amplitude (p = .0002), while no VF difference was found over the RH. Perhaps in this case, more negativity reflects the direct pathway for the LH.

Figure 12

Interaction between association and site for P230/N290 amplitudes at posterior lateral sites for word only trials



Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 3 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of site [F(2, 28)

= 11.58, p = .0002], where, once again, parietal sites showed significantly more positive amplitudes (M = 2.33 uV) as compared to temporal (M = 0.93 uV) and occipital (M = 0.44 uV) sites. There was a significant interaction of site x hemisphere [F(2, 28) = 20.37, p < .0001], which is contained within the VF x site x hemisphere interaction [F(2, 28) = 7.50, p = .0025] that is almost identical to the same interaction effect for all trials (see Figure 11). Post hoc analyses revealed more positive amplitudes across all sites and over both hemispheres for LVF presentation (p < .01 except for the RH temporal site). There was a hemispheric difference for temporal sites, which follows the same pattern discussed above for word targets, where RVF presentation resulted in a significantly more negative amplitude over the LH, while no significant VF difference was found over the RH.

Overall, parietal sites consistently showed larger positive P230/N290 amplitudes, with a further distinction made for the particular association condition. Specifically, associated word target pairs evoked larger positive amplitudes for parietal sites when compared to unassociated word target pairs. Right VF (direct) presentation for the LH temporal region resulted in a larger negative amplitude, while LVF presentation resulted in larger positive amplitudes for most sites over both hemispheres. This is surprising since indirect presentation should not yield larger amplitudes.

N400 (300-500 ms): Midline Sites

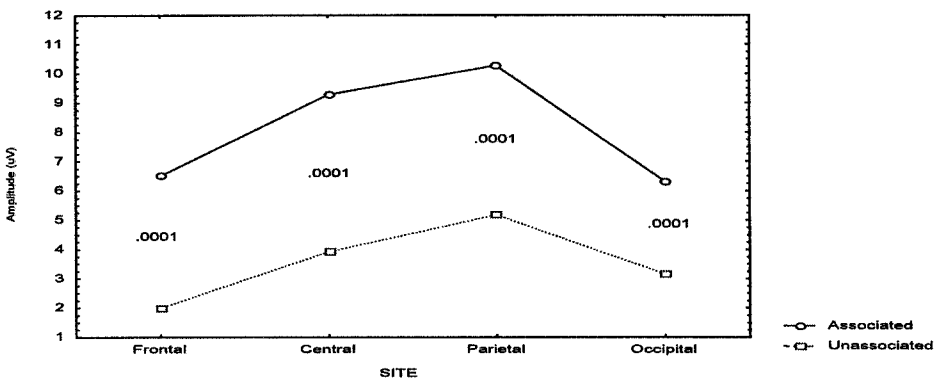
Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of word/non-word [F(1, 14) = 32.46, p

< .0001], with larger N400 amplitudes in response to non-words (M = 3.55 uV) than to words (M = 5.83). There was also a significant main effect of site [F(3, 42) = 4.90, p = .0052], with largest amplitudes over the parietal site (M = 6.50 uV). Post hoc analyses indicated that N400 amplitudes at Pz were significantly larger than Fz (M = 3.07 uV) and Oz (M = 3.81 uV), but not Cz (M = 5.39 uV). There were no significant interaction effects.

Analyses of word targets only. A 2 (association) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of association [F(1,14) = 69.04, p < .0001] with larger N400 amplitudes for unassociated prime-target pairs (M = 3.56 uV) than for associated prime-target pairs (M = 8.09 uV). There was also a significant main effect of site [F(3, 42) = 5.53, p = .0027], with post hoc analyses revealing the same pattern discussed above for word/non-words. There was a significant interaction effect between association and site [F(3, 42) = 14.83, p < .0001], which appears to be due to a smaller N400 priming effect (i.e., difference between associated and unassociated conditions) at Oz than at all other midline sites (see Figure 13). It may be the case that this difference was smallest at Oz because more visual (rather than cognitive) processing occurs in this region.

Figure 13

Interaction between association and site for N400 amplitudes at midline sites for word only trials



Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 4 (site) ANOVA yielded a significant main effect of site [$F(3, 42) = 4.20$, $p = .011$, with post hoc analyses showing larger N400 amplitudes for central and parietal sites. There was also a significant interaction for pronounceability x VF x site [$F(3, 42) = 4.90$, $p = .0052$]. Post hoc analyses revealed significant VF differences where RVF (LH) stimulus presentation resulted in larger N400 amplitudes for PNWs than for NPNWs across all sites. Left VF (RH) stimulus presentation showed the same effect at Fz only (see Figures 14 and 15).

Figure 14

Interaction of pronounceability x VF x site for N400 amplitudes at midline sites for non-word only trials

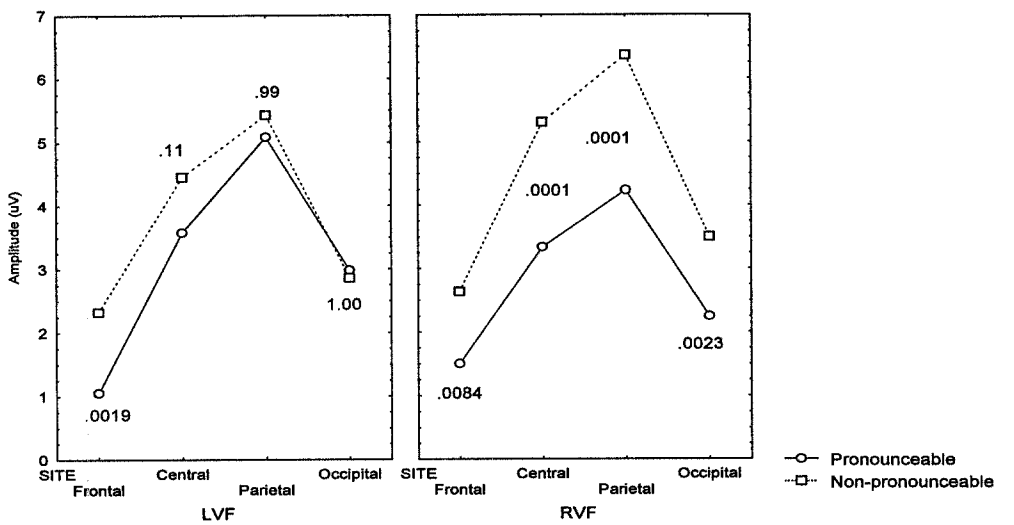
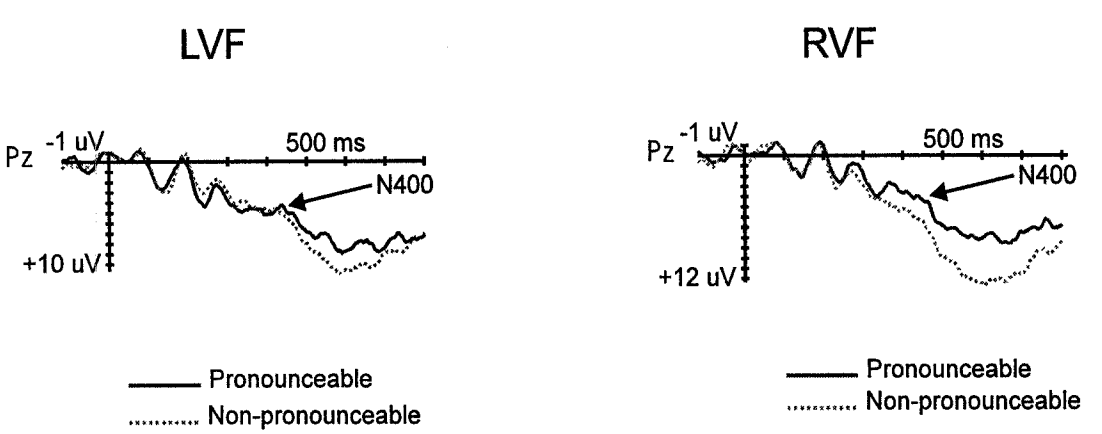


Figure 15

ERP waveforms at Pz for pronounceable versus non-pronounceable non-words by VF



N400 (300-500 ms): Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of word/non-word [$F(1, 14) = 26.58$, $p = .0002$], with larger N400 amplitudes in response to non-words ($M = 3.01$ uV) than to words ($M = 4.79$ uV). Additionally, there were significant two-way interactions for VF x hemisphere [$F(1, 14) = 19.06$, $p = .0006$], and site x hemisphere [$F(4, 56) = 6.15$, $p = .0004$], which are contained within higher order interactions. There was a significant interaction of word/non-word x site x hemisphere [$F(4, 56) = 6.57$, $p = .0002$]. Post hoc analyses revealed a significant effect of larger N400 amplitudes for non-words as compared to words, but there were no clear hemispheric findings since the word/non-word amplitude difference scores for each site did not differ more than 1 uV when compared across hemispheres (see Figure 16). Post hoc analyses for the significant interaction of VF x site x hemisphere [$F(4, 56) = 18.92$, $p < .0001$] yielded hemispheric differences where central, parietal and occipital sites showed a significantly larger N400 amplitudes for LVF (direct) presentation over the RH, but no significant VF difference over the LH (see Figure 17). Frontal sites showed the same VF difference, but it occurred over both the RH (direct pathway) and the LH (indirect pathway). Expected results were found for temporal sites, where direct VF-hemisphere combinations (RVF-LH, LVF-RH) produced larger N400 amplitudes than indirect combinations (RVF-RH, LVF-LH).

Another attempt was made to tease out potential effects of the word/non-word nested variable by using one variable (condition) with 4 levels of stimulus type: associated word (AW), unassociated word (UW), PNW, and NPNW. Since the N400 was most pronounced over parietal sites, analyses were further restricted to only include sites P3 and P4. Consequently, a 4 (condition) x 2 (VF) x 2 (site) ANOVA was conducted. Only novel effects that include the condition variable will be discussed. There was a significant main effect of condition, where UW (M = 4.73 uV), PNW (M = 4.17 uV), and NPNW (M = 5.00 uV) evoked the largest N400 amplitudes, as compared to AW (M = 8.78 uV) trials. This finding is consistent with predictions that the N400 should occur in response to unprimed target conditions and should be attenuated when priming occurs. However, it is unexpected that NPNWs would elicit an N400 similar to PNWs and UWs.

Figure 16

Interaction of word/non-word x site x hemisphere for N400 amplitudes at lateral sites for all trials

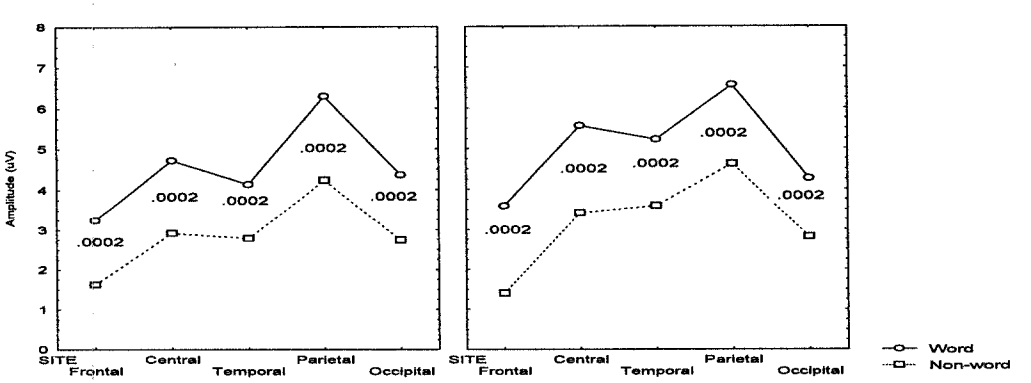
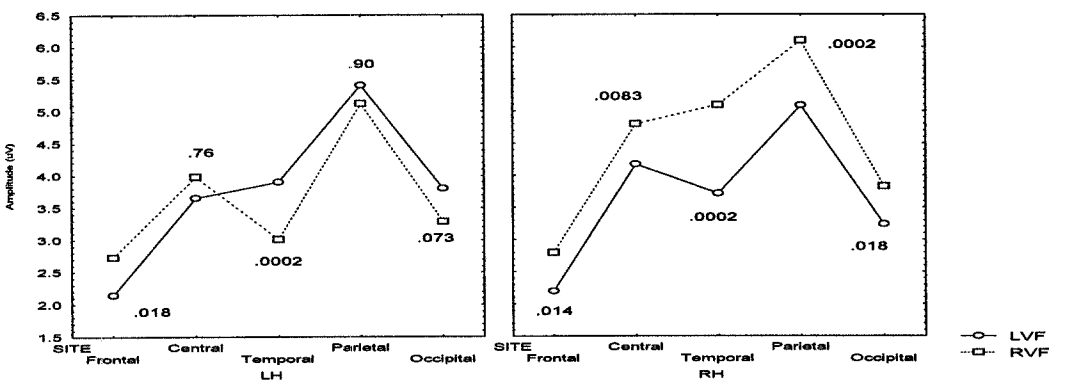


Figure 17

Interaction of VF x site x hemisphere for N400 amplitudes at lateral sites for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of association [$F(1,14) = 69.04$, $p < .0001$] with a larger N400 amplitude for unassociated prime-target pairs ($M = 3.23$ uV) than for associated prime-target pairs ($M = 6.36$ uV). There was also a significant main effect of hemisphere [$F(1, 14) = 8.79$, $p = .0102$], where N400 amplitudes were larger over the LH ($M = 4.55$ uV), than the RH ($M = 5.03$ uV). There was a significant interaction effect between association and site [$F(4, 56) = 11.86$, $p < .0001$]. Although post hoc analyses were not sensitive enough to determine the source of this effect, the difference (< 1 uV) between associated and unassociated word pairs appears smaller for temporal and occipital sites as compared to frontal, central, and parietal sites upon visual inspection. Additional two-way interactions were found for VF x hemisphere [$F(1, 14) = 12.52$, $p = .0033$], and site x hemisphere [$F(4, 56) = 6.40$, $p = .0003$], which

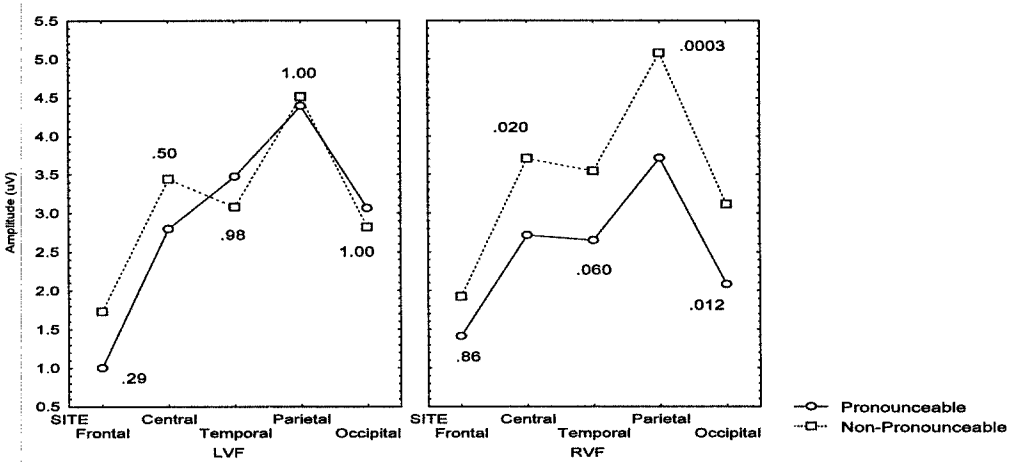
are contained within a significant interaction for VF x site x hemisphere [F(4, 56) = 12.23, p < .0001]. Post hoc analyses revealed a pattern of results consistent with the results of analyses conducted for all trials (see Figure 17), except there was no VF difference over the LH for the temporal site.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded significant interactions for VF x hemisphere [F(1, 14) = 27.67, p = .0001] and site x hemisphere [F(4, 56) = 5.95, p = .0005], which are contained within a higher order interaction. There was a significant interaction of pronounceability x VF x site [F(4, 56) = 3.98, p = .0065] that follows the same pattern for midline sites (see Figure 18). Post hoc analyses revealed a RVF (LH) effect for pronounceability, where larger N400 amplitudes were found for PNWs over all sites except frontal. There was no difference between non-word types for the LVF (RH). These results suggest that perhaps PNWs and NPNWs are processed differently by the LH, which results in an N400 only to PNWs (recall, no N400 is predicted for NPNWs), while the RH may process PNWs in a manner similar to NPNWs, resulting in an absence of the N400. Lastly, there was an interaction for VF x site x hemisphere [F(4, 56) = 20.41, p < .0001], similar to this same interaction found for all trials (see Figure 17). There was a VF difference in the expected direction, resulting in larger N400 amplitudes for direct presentation of stimuli for temporal, parietal, and occipital sites over the LH, and for temporal and parietal sites over the RH.

There were no VF differences found for frontal and central sites over both hemispheres.

Figure 18

Interaction of pronounceability x VF x site for N400 amplitudes at lateral sites for non-words only



In sum, the N400 was largest in response to pronounceable and non-pronounceable non-words and unassociated word pairs across all sites. Upon further examination of the data, a greater difference was found between unassociated and associated conditions for central and parietal sites than for temporal and occipital sites, which showed the smallest difference. In general, N400 amplitudes were largest at Pz and Cz for midline sites, and laterality effects were only found for non-words. For lateral sites, larger N400 amplitudes occurred at central, parietal, and occipital regions over the RH for LVF (direct) presentation of stimuli. Surprisingly, there were no VF differences over the LH

except for the temporal site, where direct presentation of stimuli again resulted in larger N400 amplitudes. However, upon examination of word only trials, N400 amplitudes were larger over the LH, suggesting the LH is more sensitive to association differences when processing words. Analyses of non-word target trials for midline sites resulted in larger N400 amplitudes for PNWs than NPNWs for RVF (LH) but not LVF (RH) presentations at posterior sites. Lateral sites also revealed a VF effect, where N400 amplitudes were again larger for PNWs than NPNWs presented to the RVF, while LVF presentations did not distinguish between non-word types. This finding is consistent with the prediction that PNWs would elicit larger N400 amplitudes than NPNWs, at least over the LH. Overall, direct presentation of stimuli resulted in larger N400 amplitudes which was also predicted.

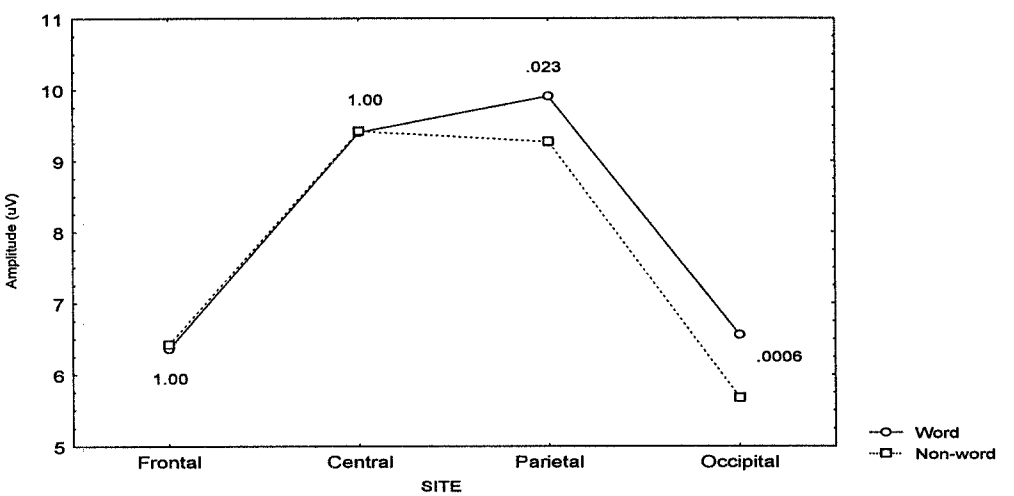
LPC (500-650 ms): Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of site [$F(3, 42) = 11.41$, $p < .0001$], with larger LPC amplitudes for central ($M = 9.41$ uV) and parietal ($M = 9.59$ uV) sites, as shown by post hoc analyses. There was also a significant interaction between the word/non-word variable and site [$F(3, 42) = 6.73$, $p = .0008$]. Post hoc tests revealed a significant difference between word and non-word stimuli for parietal and occipital sites, with larger LPC amplitudes for word stimuli which possibly reflects ease of processing (see Figure 19). These results are

consistent with the behavioral results indicating word targets produce more accurate and faster responses than non-word targets.

Figure 19

Interaction of word/non-word x site for LPC amplitudes at midline sites for all trials

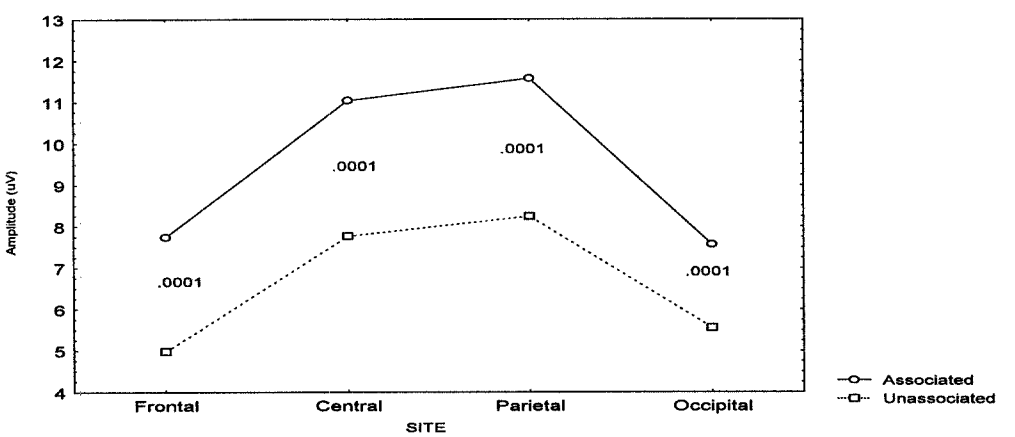


Analyses of word targets only. A 2 (association) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of association [$F(1,14) = 21.98$, $p = .0003$] with a larger LPC amplitude for associated prime-target pairs ($M = 9.48$ uV) than for unassociated prime-target pairs ($M = 6.64$ uV). There was also a significant main effect of site [$F(3, 42) = 11.92$, $p < .0001$], with post hoc analyses revealing significantly larger LPC amplitudes for central ($M = 9.40$ uV) and parietal ($M = 9.91$ uV) sites as compared to frontal ($M = 6.36$ uV) and occipital ($M = 6.56$ uV) sites. There was a significant interaction effect between association and site [$F(3, 42) = 5.59$, $p = .0026$], but post hoc analyses did not reveal the source of

this effect (see Figure 20). Upon visual inspection, LPC amplitudes appeared larger for associated as compared to unassociated word conditions at every site, and this difference tended to be largest at Cz (3.26 uV difference) and Pz (3.32 uV), while it was smallest at Oz (2.01 uV). These findings may be due to a weaker association effect for the occipital site, where more visual, rather than cognitive, processing is likely to occur.

Figure 20

Interaction between association and site for LPC amplitudes at midline sites for word only trials



Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 4 (site) ANOVA yielded a significant main effect of pronounceability [$F(1, 14) = 16.93$, $p = .0011$], with a larger LPC amplitude produced by NPNWs ($M = 9.00$ uV) than by PNWs ($M = 6.39$ uV). There was also a significant main effect of site [$F(3, 42) = 10.76$, $p < .0001$], with post hoc analyses showing larger LPC amplitudes for central and parietal sites. Lastly, there was a significant

interaction for pronounceability x VF x site [F(3, 42) = 5.840, p = .0020] that follows a similar pattern for the same interaction discussed below for lateral sites (see Figure 25). Visual inspection of this interaction suggests a larger difference between NPNW and PNW conditions for RVF (LH) presentations, so contrast analyses were performed to further explore this issue. Although there appeared to be a tendency for larger differences between PNWs and NPNWs for RVF presentations as compared to LVF presentations, no significant findings were evident across sites for this 3-way interaction (see Figure 25). In addition, NPNW stimuli evoked significantly larger LPC amplitudes over central, parietal, and occipital sites for RVF (LH) than for LVF (RH) presentation, while no such difference was found for PNW stimuli. This finding may reflect more efficient overall language processing for the LH, or perhaps the LH engages in serial processing, which facilitates the detection of differing consonants in the NPNW more quickly than for the PNW which do not violate orthographic word structure.

LPC (500-650 ms): Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of site [F(4, 56) = 5.83, p = .0005], with larger amplitudes for central (M = 7.84 uV) and parietal (M = 8.53 uV) sites, shown by post hoc analyses. There were also significant two-way interactions of word/non-word x site [F(4, 56) = 7.48, p < .0001], VF x hemisphere [F(1, 14) = 13.42, p = .0026], and site x hemisphere [F(4, 56) = 3.64, p = .010]. All of these interactions are contained within a higher order interaction,

so no further analyses were conducted for these two-way interactions. There was a significant interaction for word/non-word x site x hemisphere [$F(4, 56) = 10.01$, $p < .0001$], (see Figure 21). Visual inspection indicated larger differences between word and non-word amplitudes over the LH than the RH for temporal and parietal sites, so contrast analyses were used to compare simple interaction effects between temporal sites for left and right hemispheres for word versus non-word stimuli. The same analysis was also conducted for parietal sites. A significant laterality effect was found for both analyses, where there was a larger difference between mean wave amplitudes in response to word (larger amplitude) and non-word stimuli for the LH as compared to the RH for temporal [$F(1, 14) = 8.02$, $p = .013$] and parietal [$F(1, 14) = 7.94$, $p = .014$] sites. These results reflect enhanced processing for word stimuli over the left hemisphere for parietal and temporal sites, which are thought to be closer to regions of the brain involved in posterior language processing. There was also a significant interaction for VF x site x hemisphere [$F(4, 56) = 15.58$, $p < .0001$], where post hoc analyses revealed a significant VF effect for temporal, parietal, and occipital sites over the RH, while this difference was absent over the LH for these sites (see Figures 22 and 23). These results are surprising, since larger LPC amplitudes were found for the indirect than the direct pathway for the RH.

As described for the N400, analyses with the condition variable (AW, UW, PNW, NPNW) were performed to examine more closely the potential effects of the word/non-word nested variable. Since the LPC was most pronounced over

parietal sites, analyses were further restricted to only include sites P3 and P4. Consequently, a 4 (condition) x 2 (VF) x 2 (site) ANOVA was conducted. As before, only novel effects that include the condition variable will be discussed. There was a significant main effect of condition, where AW (M = 10.38 uV) and NPNW (M = 9.46 uV) conditions evoked the largest LPC amplitudes, which were significantly different from UW (M = 7.50 uV) and PNW (M = 6.77 uV). These results are consistent with the ease of processing interpretation of larger LPC amplitudes, since AW and NPNW conditions were less difficult for participants, based on behavioral results previously discussed.

Figure 21

Interaction between word/non-word x site x hemisphere for LPC amplitudes at lateral sites for all trials

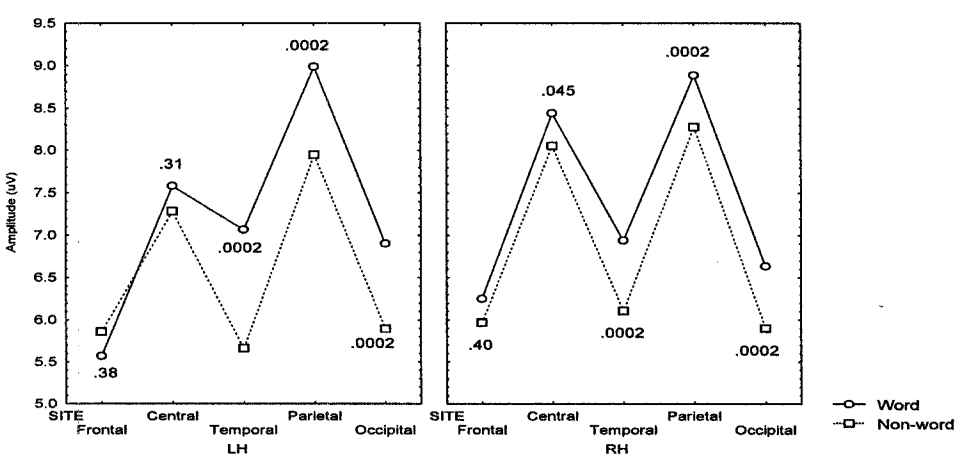


Figure 22

Interaction of VF site x hemisphere for LPC amplitudes at lateral sites for all trials

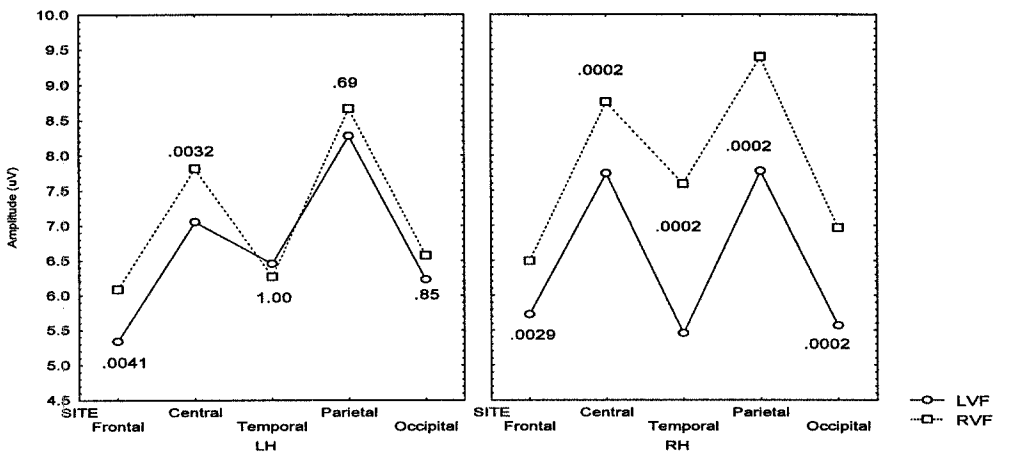
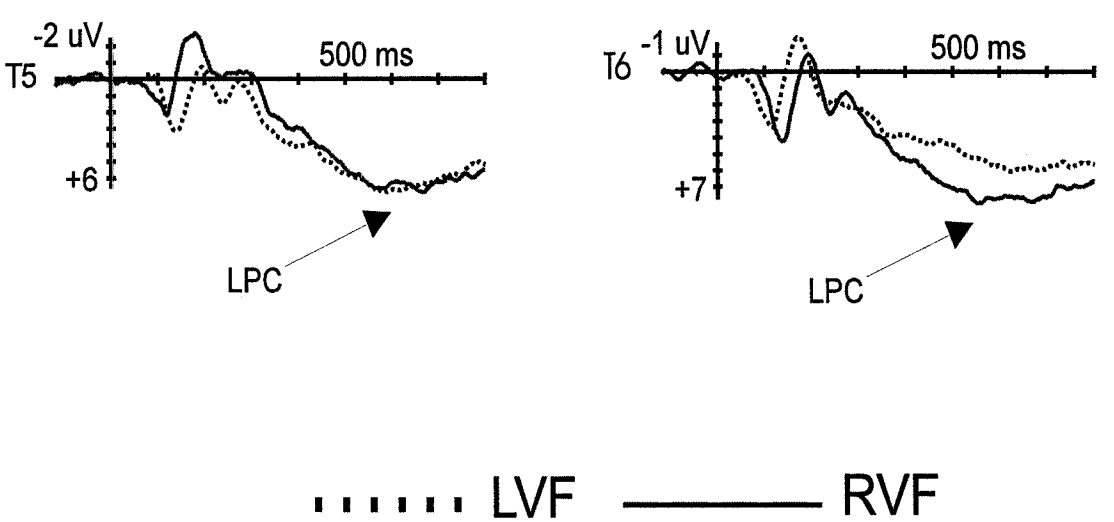


Figure 23

ERP waveforms at T5 and T6 showing overall LVF and RVF differences for the LPC

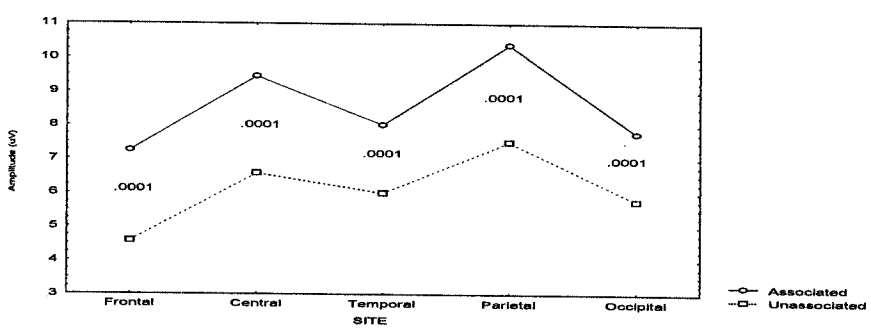


Analyses of word targets only. A 2 (association) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of association [$F(1,14) = 18.96$, $p = .0007$] with larger LPC amplitudes for associated prime-target pairs ($M = 8.57$ uV) than for unassociated prime-target pairs ($M = 6.08$ uV), likely indicating greater ease of processing for associated prime-target pairs. There was also a significant main effect of site [$F(4, 56) = 6.78$, $p = .0002$], with post hoc analyses revealing significantly greater LPC amplitudes for central ($M = 8.01$uV) and parietal ($M = 8.94$ uV) sites, as compared to frontal ($M = 5.91$ uV) and occipital ($M = 6.77$ uV) sites, with temporal sites ($M = 7.00$ uV) only differing significantly from parietal sites. There was a significant interaction effect between association and site [$F(4, 56) = 3.65$, $p = .010$], but post hoc analyses were not sensitive enough to determine the source of this effect (see Figure 24). However, differences between amplitudes for associated and unassociated conditions appeared larger for central (2.88 uV difference) and parietal (2.87 uV) sites as compared to temporal (2.02 uV) and occipital (2.00) sites upon visual inspection. Additional findings include interactions of VF x hemisphere [$F(1, 14) = 9.93$, $p = .0071$] and site x hemisphere [$F(4, 56) = 7.58$, $p = .0001$], which are both contained within the higher order interaction for VF x site x hemisphere [$F(4, 56) = 9.17$, $p < .0001$] that follows the same pattern as found for this interaction for all trials (see Figure 22). Post hoc analyses revealed the same surprising result as discussed above for the all trials analyses, where RVF (indirect) presentation of stimuli resulted in larger LPC amplitudes over the RH for

temporal, parietal, and occipital sites. No VF differences were found over the LH except for C3 where RVF (direct) presentation resulted in a larger mean amplitude, as expected.

Figure 24

Interaction between association and site for LPC amplitudes at lateral sites for word only trials

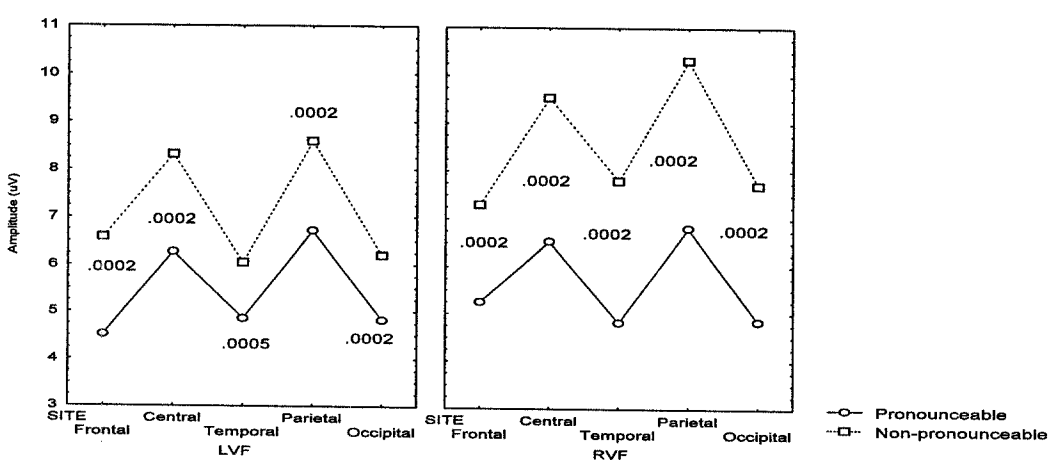


Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of pronounceability [$F(1, 14) = 15.77$, $p = .0014$], with a larger mean amplitude (M = 7.84 uV) in response to NPNWs than to PNWs (M = 5.55 uV), reflecting greater ease of processing for NPNWs. There was also a significant main effect of site [$F(4, 56) = 5.11$, $p = .0014$], with post hoc analyses showing the largest mean amplitudes for parietal sites (M = 8.11 uV) as compared to all other sites except central (M = 7.67 uV). There was a significant interaction of VF x hemisphere [$F(1, 14) = 15.83$, $p = .0014$] which is contained within a higher order interaction. There was a significant interaction for pronounceability x VF x site [$F(4, 56) =$

5.28, p = .0011], where amplitudes of NPNWs were significantly larger than PNWs across all sites, regardless of VF of presentation (see Figure 25). Post hoc analyses were not sensitive enough to discriminate any differences for pronounceable versus non-pronounceable target stimuli between LVF and RVF presentation, so contrast analyses were conducted for each site. No significant VF differences were found for pronounceable versus non-pronounceable non-word stimuli. Lastly, there was a significant interaction of VF x site x hemisphere [F(4, 56) = 16.48, p < .0001], yielding the same surprising results previously discussed, where the RVF (indirect) presentation elicited larger mean amplitudes across all RH sites (see Figure 22). Over the LH, the expected RVF advantage occurred for frontal and central sites, while there were no VF differences for posterior sites.

Figure 25

Interaction of pronounceability x VF x site for LPC amplitudes at lateral sites for non-word only trials



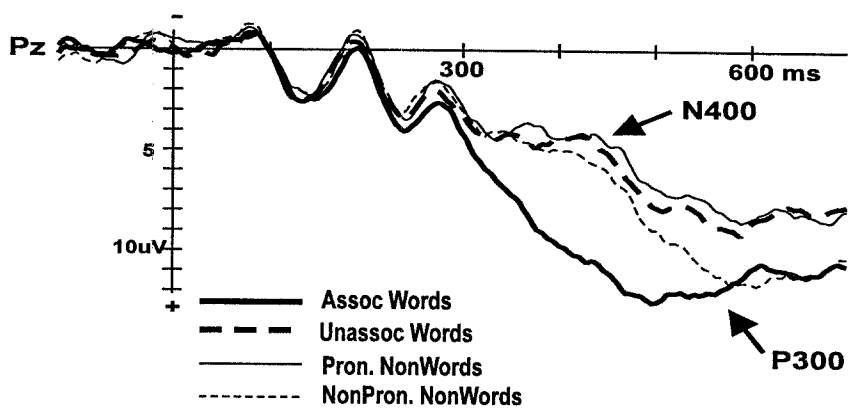
The LPC component was largest over all central and parietal sites, consistent with earlier predictions. For all trials, LPC amplitudes were greater for posterior sites in response to word stimuli, as compared to non-word stimuli. Analyses of word only trials yielded larger LPC amplitudes for associated than for unassociated target word trials, which is consistent with a late positivity being an indication of ease of processing. Additionally, the difference between associated and unassociated word target trials was largest at all central and parietal sites where the LPC has been shown to be most pronounced, and smallest at all temporal and occipital sites. Non-word trials showed larger LPC amplitudes for NPNWs than for PNWs, consistent with ease of processing since these findings correlate with the behavioral results. Lastly, a surprising yet consistent effect emerged for lateral sites across all analyses, where RVF (indirect) presentation of stimuli over the RH elicited the largest LPC amplitudes over all sites, but this VF effect was absent over the LH.

An interesting outcome was found for Experiment 1 upon examining later cognitive ERP components. When the pattern of N400 amplitudes for all conditions (AW, UW, PNW, NPNW) is compared with the pattern of LPC amplitudes for these conditions, a dissociation effect is found (see Figure 26). Specifically, for lexical decision, the three "unprimed" conditions (UW, PNW, NPNW) show the largest N400 amplitudes, while the "easier" conditions (AW, NPNW) show the largest LPC amplitudes. These findings further support the

notion that later ERP components are useful for measuring different cognitive processes.

Figure 26

ERP waveforms at Pz for all conditions illustrating dissociating cognitive patterns for the N400 and LPC components



EXPERIMENT 2 - LATERALIZED PRIMED DELAYED MATCHING WITH UNILATERAL T1 STIMULI

Behavioral Data

Although Experiment 2 is not a lexical decision task, the same prime word and target (T1) pairs were presented, with the addition of a second target (T2). Task demands differed, changing from lexical decision for the target, to matching between T1 and T2. Therefore, the following behavioral data will reflect cognitive processing for matching the two targets. Reaction time and accuracy scores were analyzed as described for Experiment 1, with an additional variable for the

second target [match (T1=T2) or no match (T1≠T2)] that was included for all three groups of analyses.

Analyses of All Trials

The analyses involving all trials used within-subjects factors of match, target and VF resulting in a 2 (match, no match) x 2 (word, non-word) x 2 (left, right) ANOVA. No differences were found for the match variable for both RT and accuracy measures. However, word targets elicited a faster response (M = 726 ms) than non-word targets (M = 761 ms), [$F(1, 15) = 7.27$, $p = .017$]. Responses to word targets were also more accurate (97.1% correct vs. 94.3% correct), [$F(1, 15) = 11.21$, $p = .004$]. Participants responded to RVF targets more quickly (736 ms vs. 751 ms), [$F(1, 15) = 6.73$, $p = .021$], but there was no VF advantage for accuracy. There were significant interaction effects between match and target type for both RT [$F(1, 15) = 20.98$, $p = .0004$] (see Figure 27) and accuracy [$F(1,15) = 5.55$, $p = .033$] (see Figure 28). Tukey HSD post hoc analyses for RT measures revealed an advantage for match trials with word targets, while there was no such advantage for non-word stimuli. Post hoc analyses for accuracy showed no difference between match and no match conditions for word stimuli. However, for non-word stimuli, no match trials were significantly more accurate than match trials. Responses to words were more accurate than non-words for match trials, while this advantage disappeared for no match trials. Increased processing demands for unfamiliar stimuli (non-words) may be responsible for

this lack of advantage for match stimuli, while such a match may actually facilitate processing for familiar stimuli.

Figure 27

Interaction between match and word/non-word for reaction time for all trials

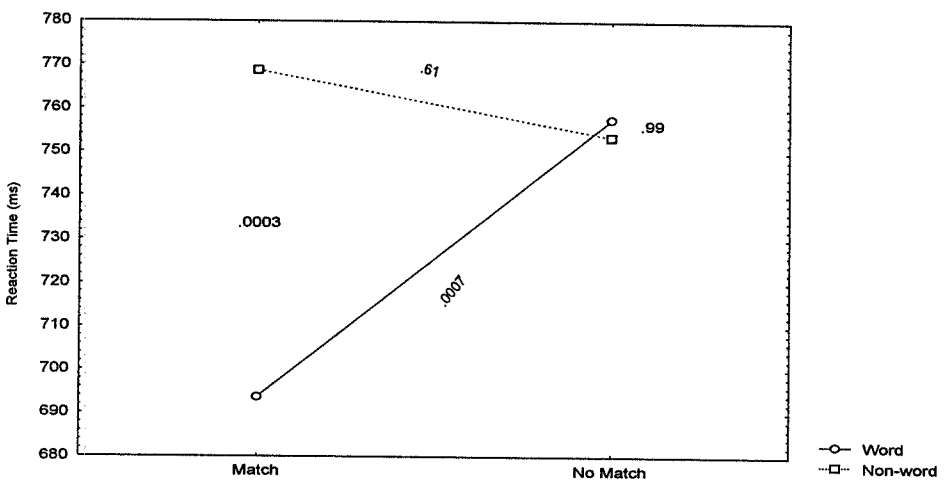
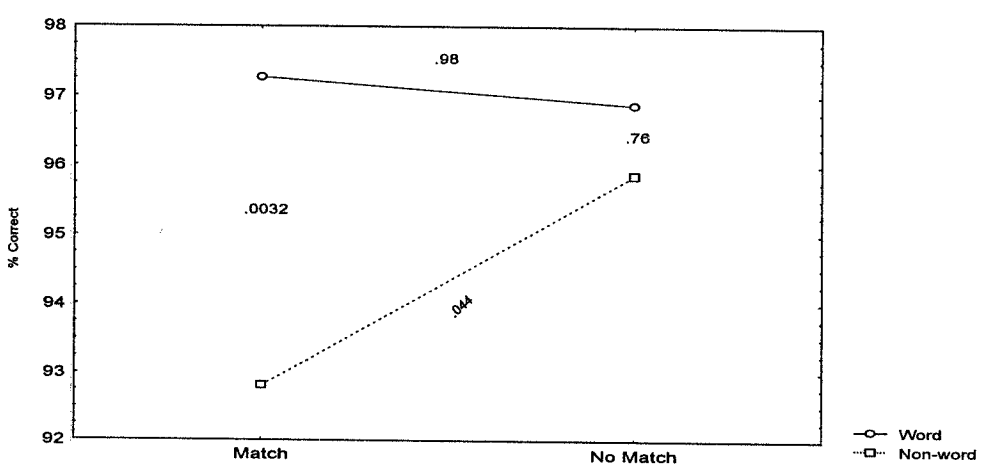


Figure 28

Interaction between match and word/non-word for accuracy for all trials



Analyses of Word Targets Only

To examine the nested factor (association/pronounceability) more closely, 2 x 2 x 2 ANOVAs were performed for word target trials by using within-subjects factors of match (match, no match), prime word type (associated, unassociated) and VF (left, right). An advantage of match over no match targets was found only for RT (M = 694 ms vs. M = 758 ms), [F(1, 15) = 13.76, p = .0021]. Additional main effects were found for accuracy, where associated word primes improved accuracy (M = 97.7%) over unassociated word primes (M = 96.5%), [F(1, 15) = 4.91, p = .043], and targets presented to the RVF (LH) improved accuracy (M = 97.8%) over those presented to the LVF (M = 96.3%), [F(1, 15) = 4.55, p = .050]. No interaction effects were found for measures of both RT and accuracy.

Analyses of Non-word Targets Only

Analyses for non-word target trials were conducted by performing 2 x 2 x 2 ANOVAs using within-subjects factors of match (match, no match), non-word target type (pronounceable, non-pronounceable) and VF (left, right). Analyses of accuracy measures revealed an advantage of no match trials (M = 95.9.8%) over match trials (M = 92.8%), [F(1, 15) = 5.66, p = .031], and for pronounceable (M = 95.3%) over non-pronounceable (M = 93.4%) non-word targets, [F(1, 15) = 4.89, p = .043]. For RT, a RVF advantage emerged (M =750 ms vs. M = 772 ms), [F(1, 15) = 4.66, p = .047]. In addition, a significant interaction between match and pronounceability was found for both RT [F(1, 15) = 7.08, p = .018]

(see Figure 29) and accuracy [F(1, 15) = 7.63, p = .015] (see Figure 30). Specifically, post hoc analyses for RT and accuracy revealed no difference between match and no match trials for PNWs, while there was an advantage of no match trials for NPNWs for RT (p = .0045) and accuracy (p = .022).

Figure 29

Interaction between match and pronounceability for reaction time for non-word only trials

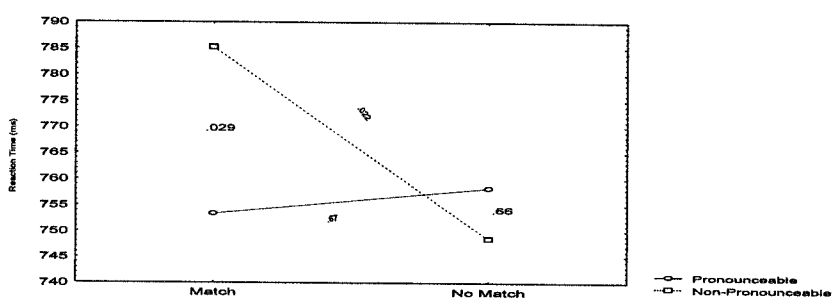
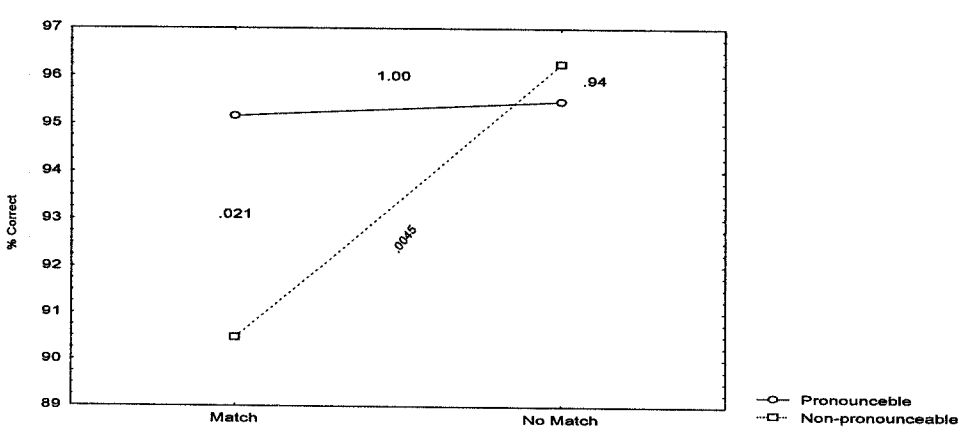


Figure 30

Interaction between match and pronounceability for accuracy for non-word only trials



Overall, word trials were faster and more accurate than non-word trials. A RVF (LH) advantage was also found for RT scores, but not for accuracy scores which may have been affected by a ceiling level. Responses to word trials were faster and more accurate when T1 matched T2, while non-word trials were more accurate when T1 did not match T2 with no difference for RT. It may be the case that familiarity with word stimuli enhances lexical decision when the words are identical and hinders performance when the words differ. Analyses of word only trials showed associated (primed) trials were more accurate than unprimed trials, as expected, and a RVF advantage emerged for accuracy. Analyses of non-word only trials showed responses to PNW trials were more accurate than NPNW trials, and an overall RVF advantage was found for RT. For PNW trials, the match variable did not have an effect, but an advantage was found for both RT and accuracy for NPNW trials when T1 did not match T2. These results support a letter by letter approach to processing unfamiliar (non-word) stimuli.

ERP Data

Figure 31 illustrates typical ERPs found from this experiment. Five ERP components were analyzed as described for Experiment 1, except different latency windows were used for these components, and additional latency windows were not necessary for anterior and posterior sites for the earlier components. As in Experiment 1, the epoch recording during T1 (not T2) was analyzed. The following analyses were conducted for the N90 (60-110 ms

latency window), P130/N190 (110-210 ms), P245/N295 (210-325 ms), N400 (325-500 ms), and LPC (500-650 ms).

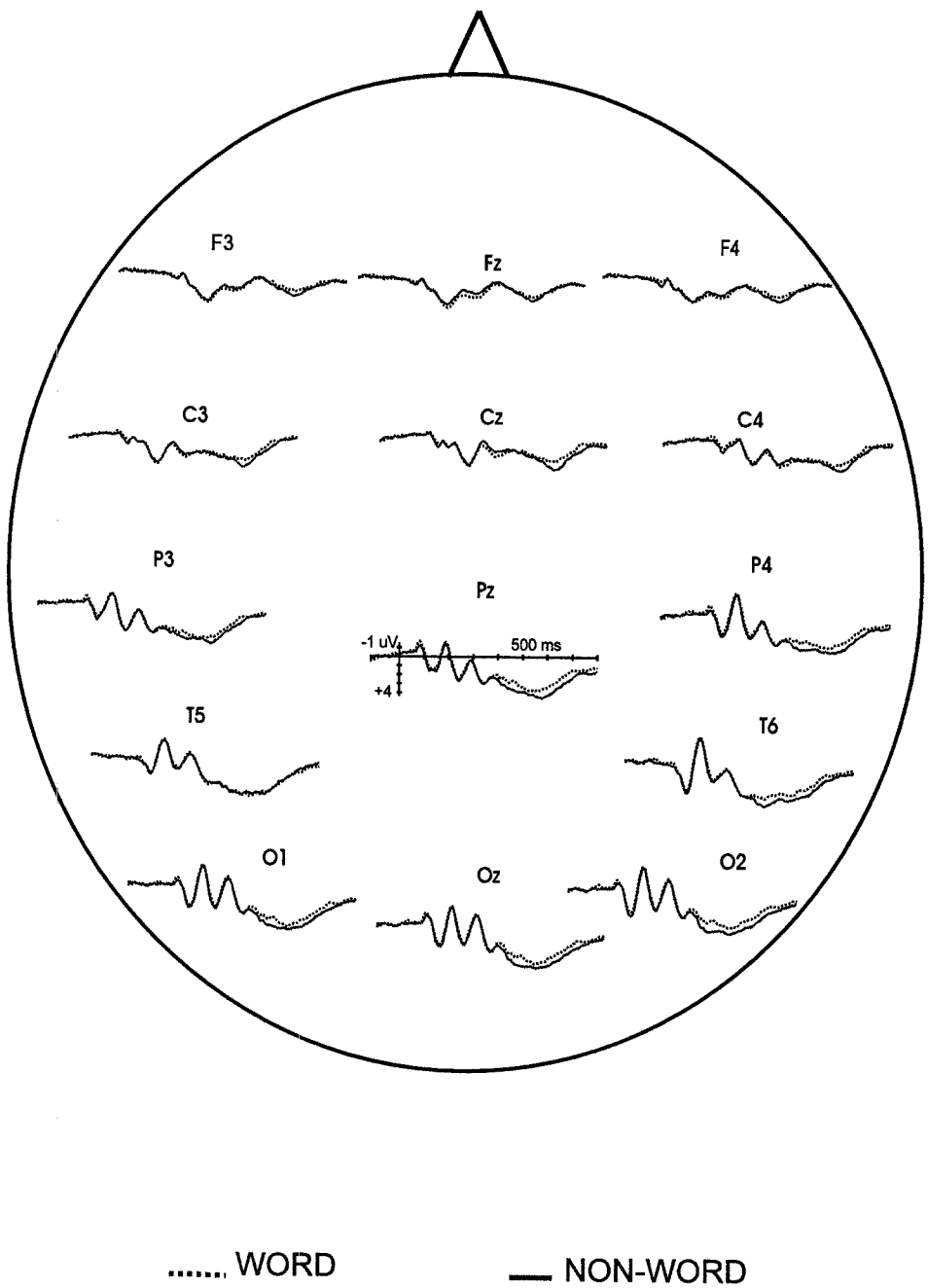
N90 (60-110 ms): Midline Sites

Analyses of all trials. A 2(word, non-word) x 2 (nested variable of association and pronounceability) x 2 (left, right VF) x 4 (Fz, Cz, Pz, Oz) ANOVA yielded a significant main effect of site [$F(3, 45) = 5.79$, $p = .0020$], where N90 amplitudes for posterior sites ($M = -0.80$ uV for Pz; $M = -0.61$ uV for Oz) were larger than for anterior sites ($M = 0.37$ uV for Fz; $M = -0.23$ uV for Cz), with post hoc analyses indicating significant differences between Fz and Pz ($p = .0021$) and Fz and Oz ($p = .012$).

Analyses of word targets only. A 2 (association) x 2 (VF) X 4 (site) ANOVA yielded a significant main effect for association [$F(1, 15) = 12.61$, $p = .0029$], where unassociated word pairs apparently evoked larger N90 amplitudes ($M = -0.91$ uV) than associated word pairs ($M = 0.085$ uV). However, this is likely a spurious finding since visual (rather than cognitive) processing should be taking place this early after stimulus presentation. There was also a significant main effect of site [$F(3, 45) = 6.99$, $p = .0006$], which follows the same pattern as described above for all trials, where posterior sites [Pz ($M = -0.98$ uV), Oz ($M = -0.70$ uV)] showed larger negative amplitudes than anterior sites [Fz ($M = 0.33$ uV), Cz ($M = -0.30$ uV)]. There was also a significant interaction of VF x site [$F(3, 45) = 4.95$, $p = .0047$]. Post hoc analyses revealed a significant VF difference for Pz and Oz, where N90 amplitudes were significantly more negative for LVF than

Figure 31

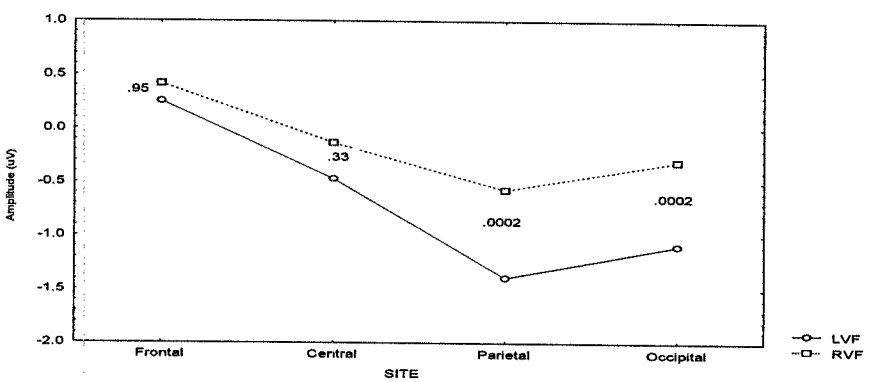
ERPs across all sites for word versus non-word stimuli in Experiment 2



RVF presentations, while this VF difference was absent for Fz and Cz (see Figure 32). These findings reflect stronger VF influences for posterior sites which is consistent with early sensory processing.

Figure 32

Interaction between VF and site for N90 amplitudes at midline sites for word only trials



Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 4 (site) ANOVA yielded no significant results.

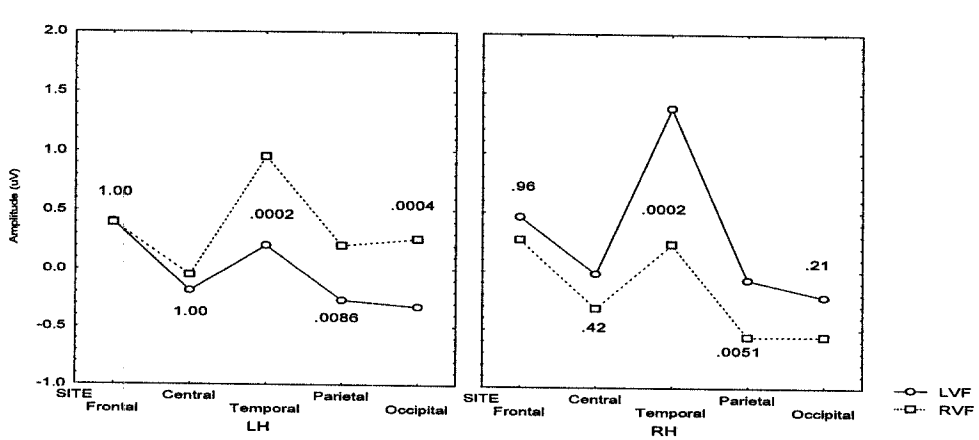
N90 (60-110 ms): Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant effect of site [$F(4, 60) = 4.93$, $p = .0017$]. Post hoc analyses revealed central ($M = -0.14$ uV), parietal ($M = -0.17$ uV), and occipital ($M = -0.21$ uV) sites showed significantly larger N90 amplitudes than temporal ($M = 0.69$ uV) sites. There were also significant interaction effects for VF x hemisphere [$F(1, 15) = 37.07$, $p < .0001$] and site x hemisphere [$F(4, 60) = 6.70$, $p = .0002$], which are both contained within the

significant higher order interaction for VF x site x hemisphere [F(4, 60) = 17.97, p < .0001]. Post hoc analyses for this interaction revealed significant VF differences for temporal, parietal, and occipital sites over the LH, and for temporal and parietal sites over the RH, where larger N90 amplitudes were recorded for indirect presentation of stimuli (ipsilateral pathway) (see Figure 33). Furthermore, temporal sites showed the largest N90 amplitudes over both hemispheres for indirect presentation of stimuli. Although these results are surprising since the direct pathway should produce a larger (negative) mean amplitude, they replicate findings for Experiment 1 for this component. Once again, this paradoxical finding may be due to dipole orientation, but these interpretations remain inconclusive since the latency of wave onset for this component is consistent with predictions that the direct (contralateral) pathway should produce earlier peak amplitudes.

Figure 33

Interaction of VF x site x hemisphere N90 amplitudes at lateral sites for all trials



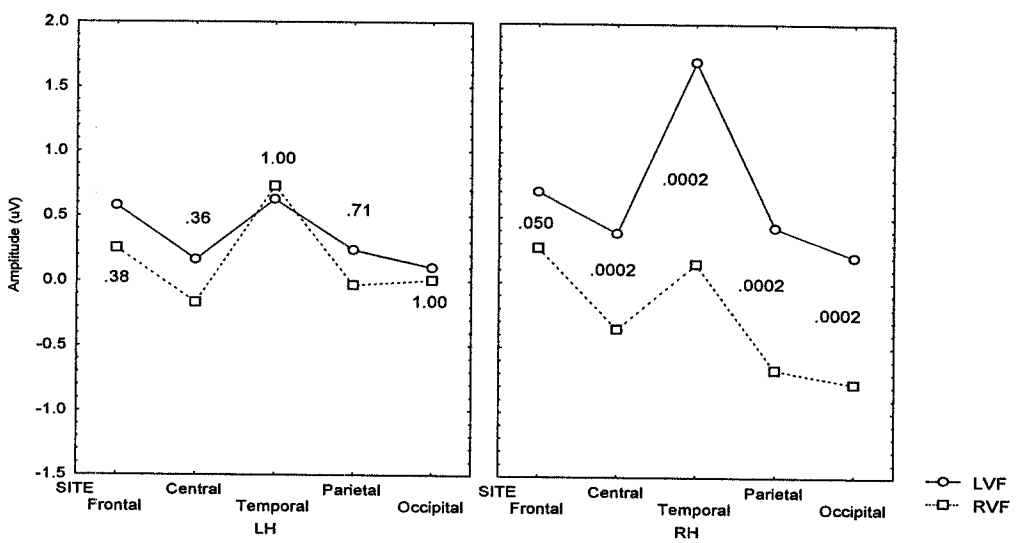
Analyses of word targets only. A 2 (association) x 2 (VF) X 5 (site) x 2 (hemisphere) ANOVA yielded results consistent with the above analyses of word and non-word targets. There was a significant main effect of site [F (4, 60) = 5.72, p = .0006], which follows the same pattern discussed above for all trials. There was also a significant main effect of association [F (1, 15) = 15.05, p = .0015], where unassociated word pairs evoked more negative amplitudes (M = -0.49 uV) than associated word pairs (M = 0.47 uV). Once again, these findings are not likely to reflect cognitive processing. Additionally, there were significant interactions for VF x hemisphere [F(1, 15) = 25.20, p = .0002] and site x hemisphere [F (4, 60) = 5.51, p = .0008], which are both contained within the interaction for VF x site x hemisphere [F(4, 60) = 18.58, p < .0001]. Post hoc analyses showed the same pattern discussed above for all trials, except there was a VF difference for the LH central site and no VF difference for the RH parietal site (see Figure 33).

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of site, consistent with the previously discussed analyses for all trials and word only trials. Again, significant interactions were found for VF x hemisphere [F(1, 15) = 27.29, p = .0001] and site x hemisphere [F(4, 60) = 6.12, p = .0003] which are both contained within the interaction for VF x site x hemisphere [F(4, 60) = 12.79, p < .0001] as shown in Figure 34. However, post hoc analyses revealed a different pattern of results for this interaction. There were no significant VF differences

over the LH, while all sites over the RH showed a significant VF difference in the unexpected direction, with ipsilateral (RVF) presentations of stimuli evoking larger N90 amplitudes.

Figure 34

Interaction of VF x site x hemisphere for N90 amplitudes at lateral sites for non-word only trials



In general, posterior sites showed larger N90 amplitudes, reflecting early visual processing. A paradoxical pattern consistent with Experiment 1 findings emerged for lateral sites where indirect (ipsilateral) presentation of stimuli resulted in larger N90 amplitudes.

P130/N190 (110-210 ms): Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 4 (site) ANOVA yielded no significant findings.

Analyses of word targets only. A 2 (association) x 2 (VF) x 4 (site) ANOVA yielded no significant findings.

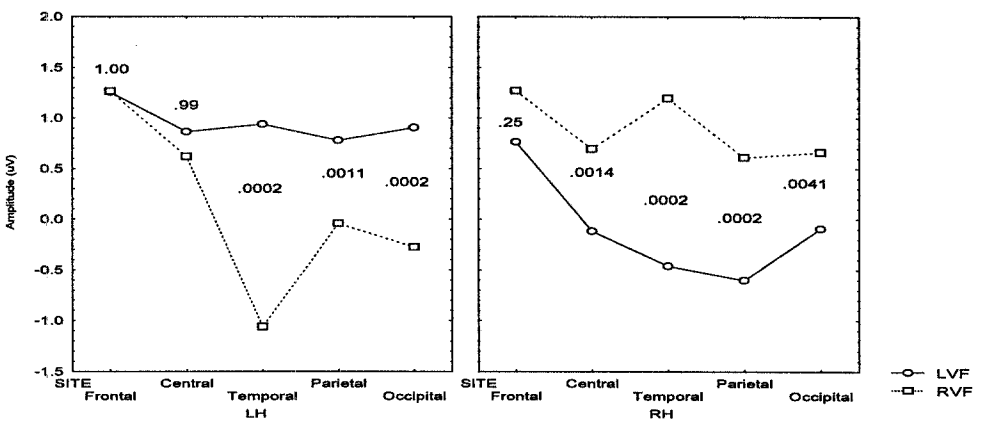
Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 4 (site) ANOVA yielded no significant findings.

P130/N190 (110-210 ms): Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded significant interactions for VF x hemisphere [$F(1, 15) = 78.26$, $p < .0001$] and site x hemisphere [$F(4, 60) = 3.69$, $p = .0094$], which are both contained within the interaction of VF x site x hemisphere [$F(4, 60) = 25.98$, $p < .0001$]. Post hoc analyses revealed VF differences for temporal, parietal, and occipital sites over both hemispheres, where direct presentation resulted in more negative amplitudes than indirect presentation (see Figure 35). Latency differences over both hemispheres for RVF and LVF presentation are in the predicted direction, where contralateral VF presentation of stimuli resulted in earlier latencies.

Figure 35

Interaction of VF x site x hemisphere for P130/N190 amplitudes at lateral sites for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) X 5 (site) x 2 (hemisphere) ANOVA yielded a significant interaction for VF x hemisphere [$F(1, 15) = 55.05$, $p < .0001$] which is contained within the interaction for VF x site x hemisphere [$F(4, 60) = 21.15$, $p < .0001$]. Post hoc analyses showed a pattern of results over the RH that is consistent with the above analyses of all trials, where contralateral VF presentation of stimuli resulted in more negative amplitudes (see Figure 35). However, over the LH, only the temporal site ($p = .0002$) followed this pattern with a significantly more negative amplitude for contralateral VF presentations.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded significant interactions for VF x hemisphere [$F(1, 15) = 85.84$, $p < .0001$] and site x hemisphere [$F(4, 60) = 3.98$, $p = .0063$] which are both contained within the interaction for VF x site x

hemisphere [F(4, 60) = 26.83, p < .0001]. Post hoc analyses revealed a similar pattern of results for this interaction, as compared to all trials and words only analyses (see Figure 35). However, VF differences occurred over the LH (more negative for RVF presentations) for all sites except frontal, and only temporal and parietal sites showed VF differences (more negative for LVF presentations) over the RH.

Overall, midline analyses for the P130/N190 yielded only insignificant findings. For lateral sites, presentation of stimuli to the direct VF evoked larger negative amplitudes while indirect presentation of stimuli evoked larger positive amplitudes over both hemispheres.

P245/N295 (210-325 ms): Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 4 (site) ANOVA yielded no significant findings.

Analyses of word targets only. A 2 (association) x 2 (VF) x 4 (site) ANOVA yielded no significant findings.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 4 (site) ANOVA yielded no significant findings.

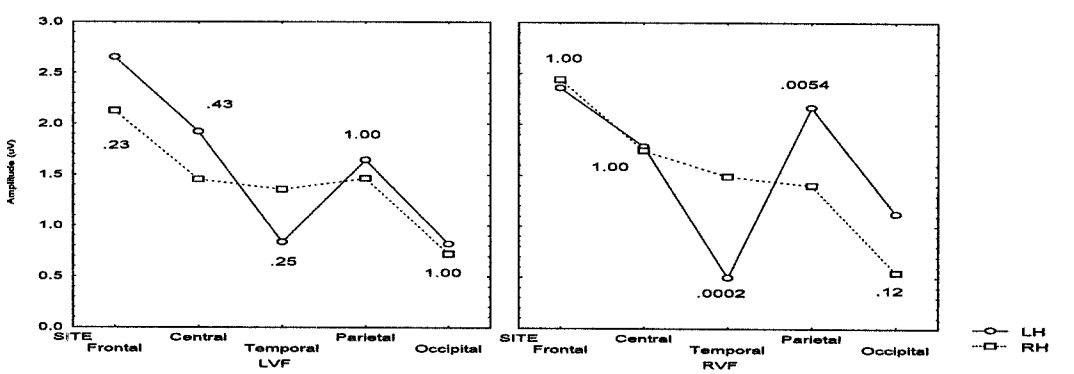
P245/N295 (210-325 ms): Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded significant interactions for site x hemisphere [F(4, 60) = 4.52, p = .0030], which is contained within the significant interaction for VF x site x hemisphere [F(4, 60) = 5.55, p = .0007]. Post hoc analyses

revealed hemispheric differences for RVF presentation, where amplitudes over the LH were more negative for temporal and more positive for parietal sites over the LH than over the RH, while there were no hemispheric differences for these sites for LVF presentation (see Figure 36). Perhaps the LH is more sensitive to contralateral VF presentation of stimuli over the sites that are typically most involved in language processing (temporal and parietal), rather than reflecting only sensory processing since this component is occurring later than the early visual components already discussed.

Figure 36

Interaction of VF x site x hemisphere for P245/N295 amplitudes at lateral sites for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) X 5 (site) x 2 (hemisphere) ANOVA yielded a significant interaction for site x hemisphere [$F(4, 60) = 4.58$, $p = .0027$] which is contained within the interaction for VF x site x hemisphere [$F(4, 60) = 6.00$, $p = .0004$]. Post hoc analyses show a pattern of results consistent with those discussed above for the all trials analyses. Again,

RVF presentations resulted in a significantly more positive amplitude for the LH parietal site, and a significantly more negative amplitude for the LH temporal site, as compared to the corresponding RH sites. No such hemispheric difference was found for LVF presentations (see Figure 36).

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant site x hemisphere interaction [$F(4, 60) = 4.29$, $p = .0041$] which is contained within the interaction for VF x site x hemisphere [$F(4, 60) = 4.37$, $p = .0036$], again, similar to the same interaction effect for the all trials analyses as shown in Figure 36. Post hoc analyses revealed only one significant VF difference (within hemispheres) for the LH, where a larger negative amplitude occurred for RVF than for LVF presentations at the temporal site.

In general, RVF presentations of stimuli resulted in larger negative amplitudes for the LH temporal site, and larger positive amplitudes for the LH parietal site, as compared to the corresponding RH sites. LVF presentations did not elicit any hemispheric differences. However, when non-words were analyzed separately, LVF presentations did show a pattern of results similar to the above, where direct presentation of stimuli resulted in a larger negative amplitude for the LH temporal site. It appears as if this component is more sensitive to RVF (LH) presentation, possibly reflecting early cognitive processing.

N400 (325-500 ms): Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of site [$F(3, 45) = 5.74$, $p = .0021$], with the largest N400 amplitudes over Fz ($M = 1.28$ uV) and Cz ($M = 1.57$ uV), as compared with Pz ($M = 2.83$ uV) and Oz ($M = 3.20$ uV) which was confirmed by post hoc analyses ($p \leq .03$). There was also a significant interaction between word/non-word and site [$F(3, 45) = 5.10$, $p = .0040$], where word targets (T1) tended to evoke larger N400 amplitudes than non-word targets for Pz and Oz. However, these differences did not reach significance.

Analyses of word targets only. A 2 (association) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of association [$F(1,15) = 13.82$, $p = .0021$] with a larger N400 amplitude for unassociated prime-target pairs ($M = 1.25$ uV) than for associated prime-target pairs ($M = 3.06$ uV), as predicted. There were no other significant findings.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 4 (site) ANOVA yielded a significant main effect of site [$F(3, 45) = 9.12$, $p = .0001$], with post hoc analyses showing larger N400 amplitudes for frontal ($M = 1.13$ uV) and central ($M = 1.51$ uV) sites as compared to parietal ($M = 3.07$ uV) and occipital ($M = 3.47$ uV) sites. There were no other significant findings.

N400 (325-500 ms): Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of site [$F(4, 60) =$

7.42, p = .0001], with largest N400 amplitudes over frontal (M = 1.43 uV) and central (M = 1.98 uV) sites, as compared to temporal (M = 3.57 uV), parietal (M = 3.05 uV), and occipital (M = 3.36 uV) sites ($p \leq .014$) . There were significant interactions for word x site [$F(4, 60) = 3.72$, p = .0091], and VF x hemisphere [$F(1, 15) = 9.36$, p = .0080], which will be interpreted within significant higher order interaction effects. There was a significant interaction for word/nonword x site x hemisphere [$F(4, 60) = 5.51$, p = .0008], with post hoc analyses revealing significantly larger amplitudes for words than for non-words for parietal and occipital sites over the LH, and for temporal, parietal, and occipital sites over the RH (see Figure 37). However, these differences were small (less than 1 uV). Post hoc analyses of the significant interaction for VF x site x hemisphere [$F(4, 60) = 19.38$, $p < .0001$], yielded paradoxical findings, whereby stimuli presented to the ipsilateral VF produced a larger N400 for temporal sites over both hemispheres and for the LH occipital site (see Figure 38).

As described for the N400 and LPC components in Experiment 1, analyses with the condition variable (AW, UW, PNW, NPNW) were performed to examine more closely the potential effects of the word/non-word nested variable. To be consistent with previous analyses, only sites P3 and P4 were included, resulting in a 4 (condition) x 2 (VF) x 2 (site) ANOVA. As before, only novel effects that include the condition variable will be discussed. There was a significant main effect of condition, where UW (M = 1.86 uV) elicited the largest N400 amplitudes, and significantly differed from both AW (M = 3.88 uV) and

NPNW (M = 3.63 uV), but not PNW (M = 2.82 uV). Conditions AW, PNW, and NPNW did not differ from one another according to post hoc analyses. This finding is consistent with predictions that the N400 should occur in response to unprimed target conditions and should be attenuated when priming occurs. However, it is unexpected that PNW and NPNW conditions did not differ from one another, since generally PNWs have been shown to elicit the N400 and NPNWs have not.

Figure 37

Interaction of word/non-word x site x hemisphere for N400 amplitudes at lateral sites for all trials

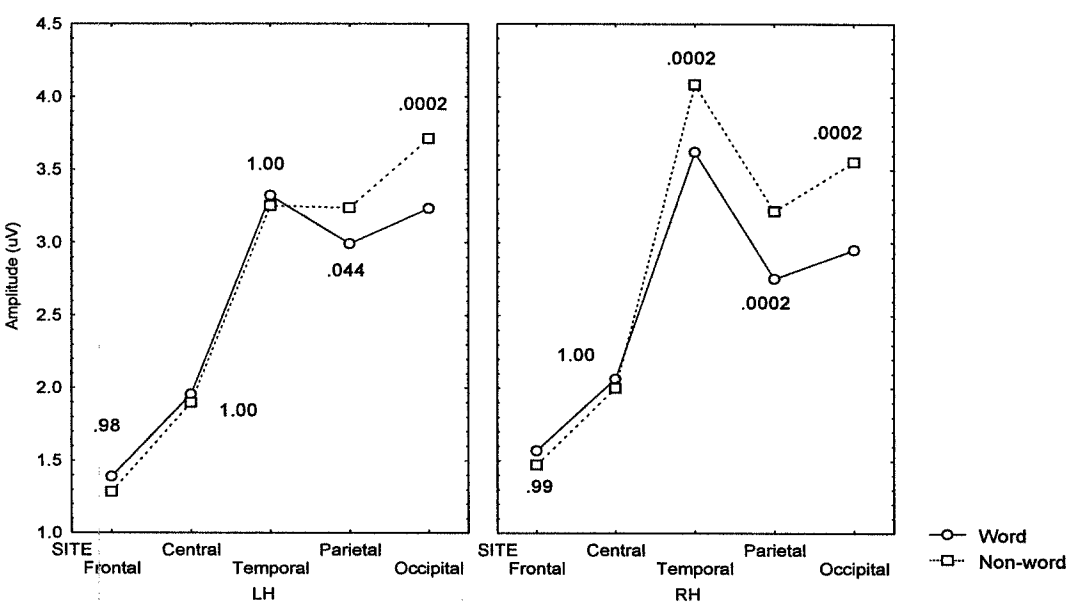
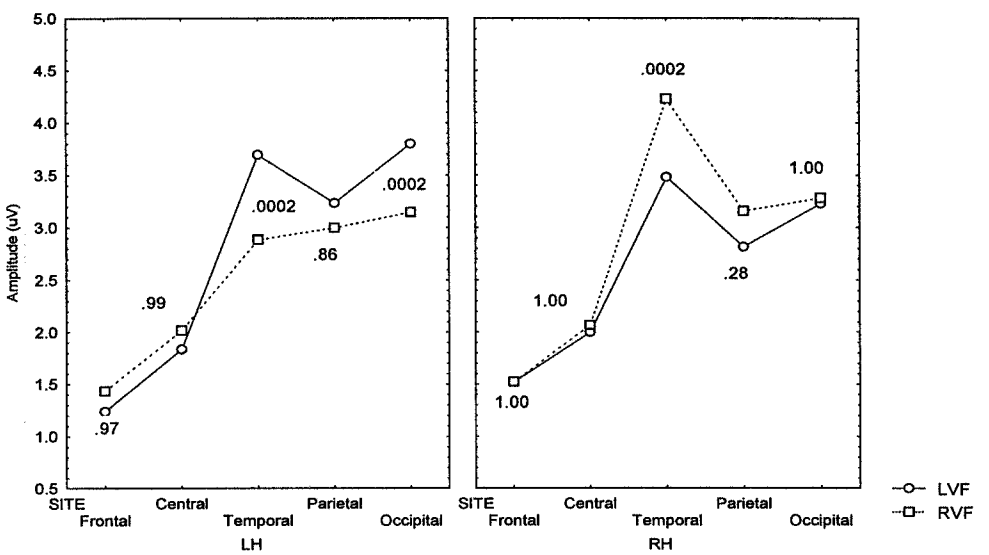


Figure 38

Interaction of VF x site x hemisphere for N400 amplitudes at lateral sites for all trials



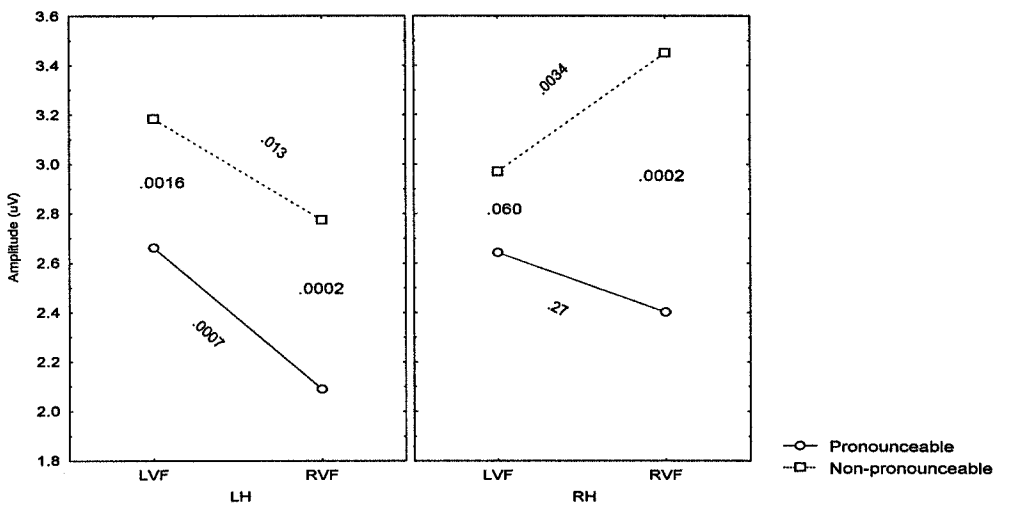
Analyses of word targets only. A 2 (association) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of association [$F(1, 15) = 14.02$, $p = .0020$] with a larger N400 amplitude for unassociated prime-target pairs ($M = 1.74$ uV) than for associated prime-target pairs ($M = 3.43$ uV). There was also a significant main effect of site [$F(4, 60) = 5.28$, $p = .0010$], with post hoc analyses revealing the same pattern discussed above for word/non-words. There was a significant interaction for VF x site x hemisphere [$F(4, 60) = 13.00$, $p < .0001$], similar to the same interaction for all trials analyses, with the largest amplitude occurring over temporal sites where stimuli presented to the

contralateral (direct pathway) produced a larger N400 over both hemispheres and for the LH occipital site (see Figure 38).

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of site [$F(4, 60) = 9.48$, $p < .0001$], where frontal ($M = 1.38$ uV) and central ($M = 1.95$ uV) sites had larger N400 amplitudes than temporal ($M = 3.67$ uV), parietal ($M = 3.23$ uV), and occipital ($M = 3.63$ uV) sites. There was an interaction for pronounceability x VF x hemisphere [$F(1, 15) = 8.31$, $p = .011$] that approached significance (see Figure 39). Post hoc analyses revealed an overall significant difference where NPNWs had smaller N400 amplitudes than PNWs, as expected. Surprisingly, this difference did not reach significance for LVF presentation over the RH (direct input) since the amplitude for the PNW condition was smaller than expected (see Figure 39). Lastly, there was a significant interaction for VF x site x hemisphere [$F(4, 60) = 18.43$, $p < .0001$], similar to the all trials results (see Figure 38). Post hoc analyses revealed a VF difference, where the direct pathway produced a larger N400 over the LH for posterior sites, while this effect only occurred over the temporal site for the RH.

Figure 39

Interaction of pronounceability x VF x hemisphere for N400 amplitudes at lateral sites for non-word trials only



Overall, N400 amplitudes were greatest over all anterior sites for all trials. Unprimed (unassociated) word target trials and PNW trials also resulted in larger N400 amplitudes, as expected. Direct presentation of stimuli to the hemispheres generally resulted in larger N400 amplitudes as well. Finally, N400 amplitudes were larger for PNWs than for NPNWs except for RH recordings with LVF (RH) presentations. This is consistent with findings from Experiment 1, where a lack of pronounceability effects was found for the RH.

LPC (500-650 ms): Midline Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of site [$F(3, 45) = 10.24$, $p < .0001$], with larger amplitudes for parietal ($M = 3.73$ uV) and occipital ($M = 3.88$ uV) sites

as compared to frontal (M = 1.87 uV) and central (M = 2.49 uV) sites, confirmed by post hoc analyses (all p values < .05). There were no significant interaction effects.

Analyses of word targets only. A 2 (association) x 2 (VF) x 4 (site) ANOVA revealed a significant main effect of site [F(3, 45) = 8.10, p = .0002], with post hoc analyses revealing the same pattern as discussed above where amplitudes for central and parietal sites were significantly larger (all p values < .052). There were no significant interaction effects.

Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 4 (site) ANOVA yielded a significant main effect of site [F(3, 45) = 10.61, p < .0001], with post hoc analyses again revealing the same pattern where amplitudes for central and parietal sites were significantly larger (all p values < .05). There were no significant interaction effects.

LPC (500-650 ms): Lateral Sites

Analyses of all trials. A 2 (word, non-word) x 2 (nested) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of site [F(4, 60) = 10.95, p < .0001], with larger amplitudes for temporal (M = 3.59 uV), parietal (M = 3.49 uV) and occipital (M = 3.99 uV) sites, as compared with frontal (M = 1.99 uV) and central (M = 2.41 uV) sites (all p values < .05). There were significant interactions for VF x hemisphere [F(1, 15) = 10.23, p = .0060] and word/non-word x site x hemisphere [F(4, 60) = 11.69, p < .0001], which are contained within the significant interaction of word/non-word x VF x site x hemisphere [F(4, 60) = 3.77,

p = .0084] (see Figure 40). For non-words, LH recordings revealed larger LPC amplitudes to indirect-LVF stimuli, than to direct-RVF stimuli at all but frontal sites. For words, this pattern differed for LH recordings showing larger LPC amplitudes to indirect-LVF stimuli, than to direct-RVF stimuli for only temporal and occipital sites. This effect also tended to be smaller for word stimuli (less than 1 uV), as compared to non-word stimuli. To examine this 4-way interaction more closely, patterns occurring at each site will be discussed separately. For temporal sites, LPC amplitudes were always larger for indirect VF-hemisphere than for direct VF-hemisphere conditions, indicating systematic, paradoxical lateralization for both word and non-word conditions (see Figure 40). At occipital sites there was also a paradoxical VF-hemisphere effect, but only for the LH, possibly indicating hemispheric differences for processing both word and non-word stimuli. Parietal sites show a condition specific paradoxical VF-hemisphere effect, occurring only at RH sites for words and only at LH sites for non-words. Effects at central sites also depend upon stimulus type, where a RVF advantage occurs over both hemispheres for word stimuli, while a LVF advantage occurs over both hemispheres for non-word stimuli. Lastly, frontal sites show the same trend as central sites.

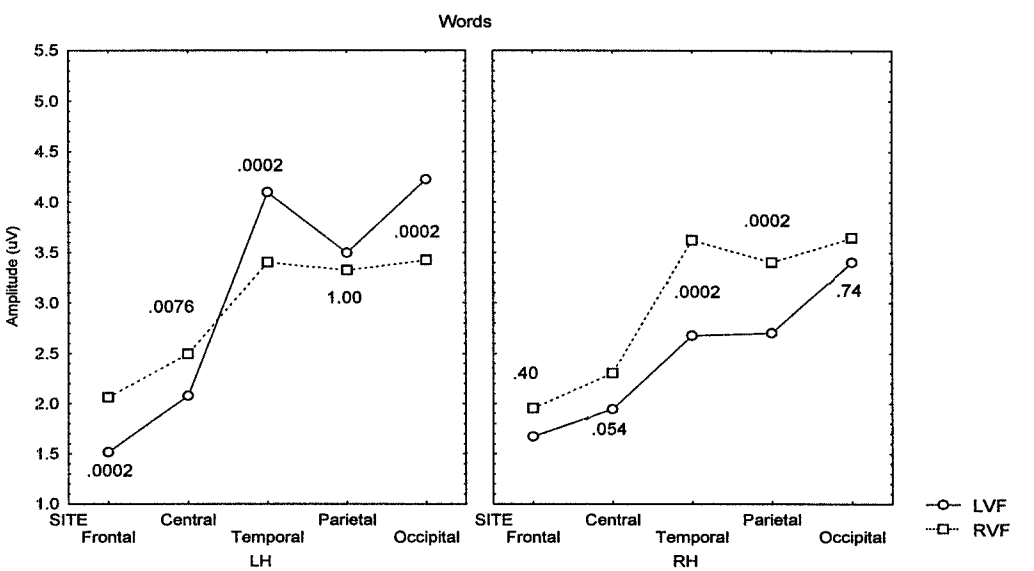
As described above for the N400, analyses with the condition variable (AW, UW, PNW, NPNW) were performed for LPC amplitudes to further investigate the word/non-word nested variable. Again, only amplitudes at sites P3 and P4 were analyzed, resulting in a 4 (condition) x 2 (VF) x 2 (site) ANOVA.

As before, only novel effects that include the condition variable will be discussed. There was a significant interaction effect between condition and site (see Figure 41), showing larger LPC amplitudes for condition AW over the LH (P3) as compared to the RH (P4) at parietal sites, according to post hoc analyses. Conditions AW (M = 10.38 uV) and NPNW (M = 9.46 uV) evoked the largest LPC amplitudes, which were significantly different from UW (M = 7.50 uV) and PNW (M = 6.77 uV). These results are consistent with the ease of processing interpretation of larger LPC amplitudes, since AW and NPNW conditions were less difficult for participants, based on behavioral results previously discussed. Also, there was a larger amplitude difference between AW and UW over the LH (P3) than the RH (P4), indicating greater sensitivity of the LH to semantic priming.

Figure 40

Interaction of word/non-word x VF x site x hemisphere for LPC amplitudes at lateral sites shown for (A) words and (B) non-words

(A)



(B)

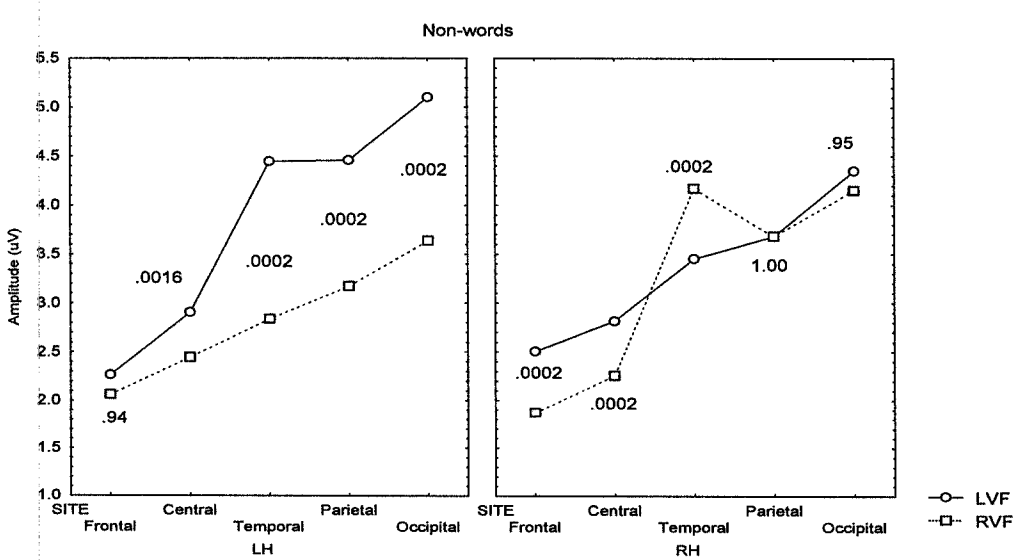
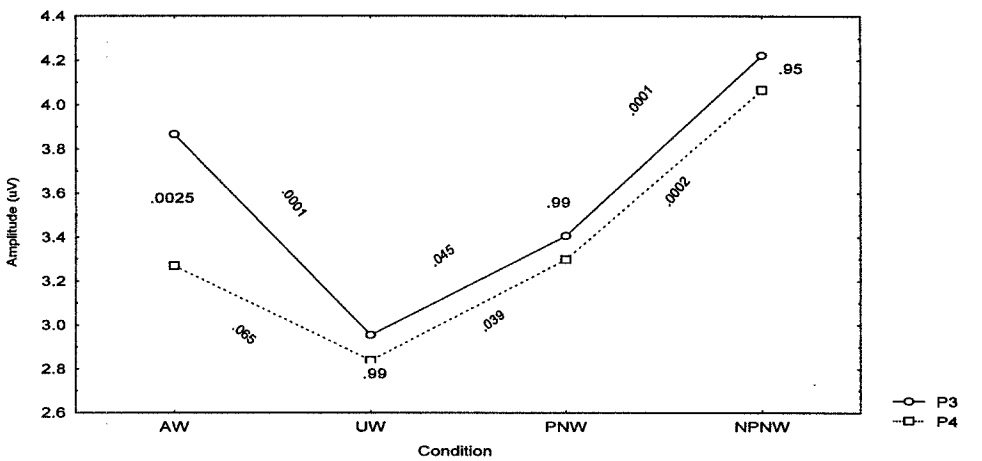


Figure 41

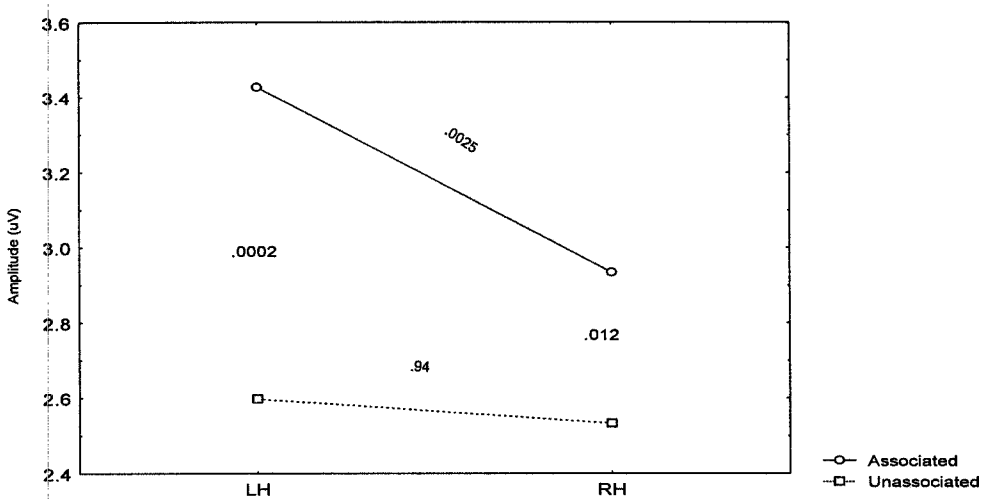
Interaction between condition and site for LPC amplitudes at P3 and P4 for all trials



Analyses of word targets only. A 2 (association) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of site [$F(4, 60) = 9.99$, $p < .0001$], with post hoc analyses revealing the same pattern found in the above analysis, where posterior amplitudes where significantly larger than anterior amplitudes. The interaction between association and hemisphere approached significance [$F(1, 15) = 7.44$, $p = .016$]. Post hoc analyses revealed significantly larger LPC amplitudes for associated as compared to unassociated conditions, and this difference was larger over the LH than the RH (see Figure 42). There was also a significant interaction for VF x site x hemisphere [$F(4, 60) = 16.96$, $p < .0001$] which has already been discussed (see Figure 40A).

Figure 42

Interaction between association and hemisphere for LPC amplitudes at lateral sites for word only trials



Analyses of non-word targets only. A 2 (pronounceability) x 2 (VF) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of site [$F(4, 60) = 10.40$, $p < .0001$], with post hoc analyses showing a similar pattern to the all trials and word only analyses, where posterior sites showed the largest mean amplitudes. There was a significant interaction of VF x hemisphere [$F(1, 15) = 9.66$, $p = .0072$] which is contained within the higher order interaction of VF x site x hemisphere [$F(4, 60) = 35.89$, $p < .0001$]. This interaction has also been previously discussed (see Figure 40B).

In sum, LPC amplitudes were attenuated as expected by this task, but surprisingly, significant effects were found for this component. The LPC appears to reflect different types of processing over different scalp sites, supporting the

notion of multiple generators for this component. For temporal sites, there was a paradoxical advantage for indirect VF-hemisphere presentations of stimuli. Occipital sites showed this same effect, but only over the LH, suggesting a hemispheric difference. However, parietal and frontal regions showed word/non-word effects, indicating sensitivity to linguistic manipulations. LPC amplitudes were also significantly larger for the associated as compared to the unassociated condition over the LH, while there was no difference of association over the RH (see Figure 42). This finding suggests the LH is more sensitive than the RH to semantic priming.

EXPERIMENT 3 - LATERALIZED PRIMED DELAYED MATCHING WITH BILATERAL T1 STIMULI

Behavioral Data

This task is similar to the delayed matching task, except only word stimuli were used, and T1 stimuli were presented bilaterally as either identical or different word pairs. Reaction time and accuracy scores were analyzed as described for Experiment 2. However, the variables changed because of (a) bilateral presentation of T1 stimuli, and (b) a lack of non-word targets in this experiment. The first set of analyses included two variables: 1) match, which has two levels [match (T1/LVF or T1/RVF = T2) or no match (T1/both VFs $\neq$ T2)], and 2) condition, which has 5 levels for T1 [IA (identical and associated words for both VFs), IU (identical and unassociated words for both VFs), LARU (LVF associated word, RVF unassociated word), LURA (LVF unassociated word, RVF

associated word), and DU (different unassociated words for each VF)]. The second set of analyses examined only non-identical match trials (i.e., LVF ≠ RVF), and the match variable was replaced with a visual field match variable (VF match), which has 2 levels (LVF T1 = T2, RVF T1 = T2), and the condition variable has 3 levels in this case (LARU, LURA, and DU).

Analyses of All Trials

Within-subjects factors of condition and match were used, resulting in a 5 (IA, IU, LARU, LURA, DU) x 2 (match, no match) ANOVA. There was a significant main effect for match [$F(1, 17) = 8.78$, $p = .0087$], where match responses were faster ($M = 728$ ms) than no match responses ($M = 772$ ms). However, accuracy data reflect the opposite finding [$F(1, 17) = 7.95$, $p = .012$], where the no match condition yielded more accurate ($M = 94.8\%$) performance than the match condition ($M = 91.3\%$). There was also a significant main effect for condition [$F(4, 68) = 51.70$, $p < .0001$] where identical bilateral T1 stimuli (IA, IU) resulted in faster responses ($M = 693$ ms) than different bilateral T1 stimuli (LARU, LURA, DU; $M = 788$ ms), which did not significantly differ from one another according to Tukey HSD post hoc analyses. Accuracy data correlate with these results, where performance for IA and IU conditions was more accurate ($M = 97.2\%$) than performance for LARU, LURA, and DU conditions ($M = 90.3\%$; $p \leq .0037$). However, performance for LARU stimuli was significantly more accurate than DU (but not different from LURA) stimuli, while LURA and DU conditions did not differ significantly. There was a significant interaction

between match and condition for RT [F(4, 68) = 5.96, p = .0004], where post hoc analyses revealed that the match condition significantly improved RT over the no match condition for IA and IU conditions (see Figure 43). In contrast, there were no significant differences for the match condition for LARU, LURA, and DU stimuli. For accuracy data, there was also a significant match x condition interaction [F(4, 68) = 6.83, p = .0001] (see Figure 44). In this case, there was no difference between match and no match conditions for IA and IU stimuli, but this may be due to a ceiling effect for accuracy. However, a difference emerged for the remaining conditions, where LURA performance was significantly worse for the match than for the no match condition, and LARU and DU conditions (which did not differ from each other), showed no significant effects for match.

Figure 43

Interaction between match and condition for reaction time for all trials

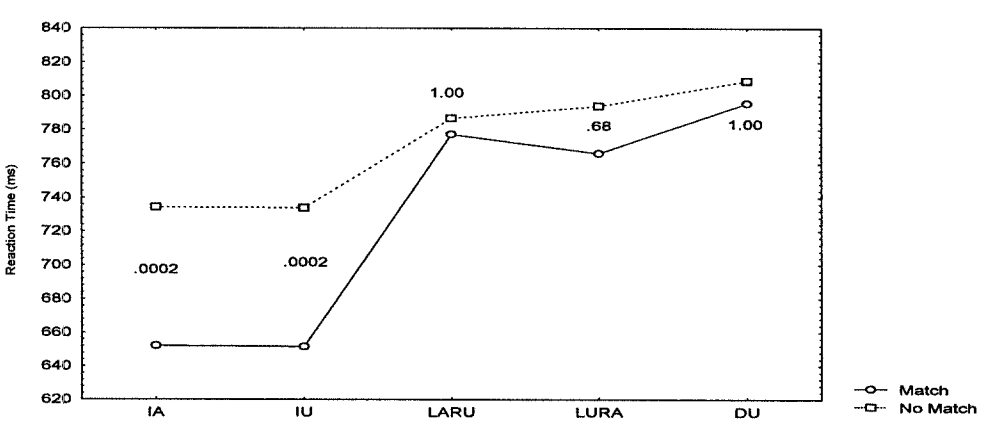
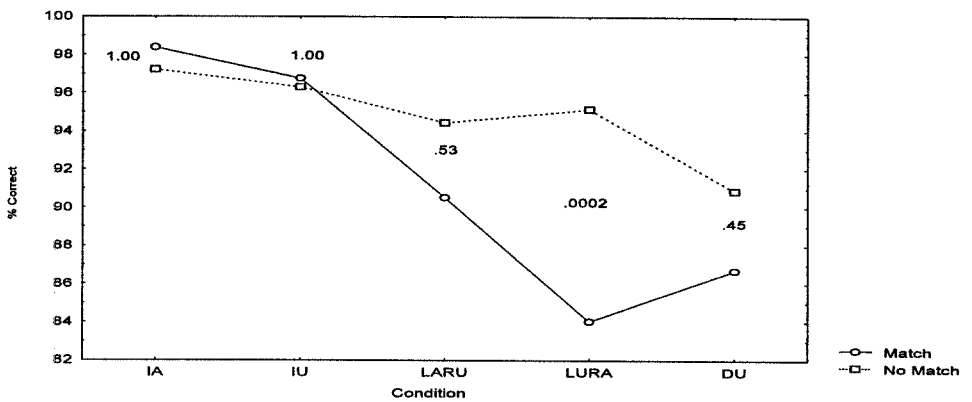


Figure 44

Interaction between match and condition for accuracy for all trials



Overall, participants responded more quickly to match trials, but accuracy was higher for no match trials, suggesting there may be a speed-accuracy trade off. When the different conditions are considered, identical stimuli in the VFs improves both RT and accuracy. There were also significant interactions between match and condition for RT and accuracy. Match trials improved RT for conditions IA and IU, but this effect was absent for accuracy. It appears these data reflect a simple redundancy effect, rather than effects of association or association x VF, where performance for identical stimuli in the VFs differs from performance for different stimuli in the VFs. Furthermore, these results support a level of processing hierarchy where redundancy effects prevail over association effects since redundant stimuli are simpler to process than the associated/unassociated distinction. For accuracy data, the match condition lowered accuracy for LURA, while LARU and DU conditions showed no effect. Further analyses of these data is necessary to determine whether the VF where

the target matched is affecting this outcome. For example, poor performance for the match condition for LURA stimuli may be due to matching occurring in the LVF (RH) instead of in the RVF (LH). For LURA stimuli, the LH is primed since the RVF receives the associated prime word, but this may hurt performance if matching occurs in the LVF (RH). The next set of analyses addresses this issue.

Analyses of VF Match Trials

Within-subjects factors of condition and VF match were used, resulting in a 3 (LARU, LURA, DU) x 2 (LVF match, RVF match) ANOVA. There was a significant main effect for VF match [$F(1, 17) = 14.45$, $p = .0014$], where RVF (LH) match responses were faster ($M = 747$ ms) than LVF (RH) match responses ($M = 825$ ms). Accuracy data correlate with these findings, with a significant main effect of VF match [$F(1, 17) = 23.28$, $p = .0002$], where RVF match responses were more accurate ($M = 93.8\%$) than LVF match responses ($M = 80.4\%$). In addition, accuracy data yielded a significant main effect of condition [$F(2, 34) = 5.52$, $p = .0084$]. Post hoc analyses revealed LARU (RH primed) responses were significantly more accurate than LURA and DU, which did not significantly differ from one another.

There was a significant interaction between VF match and condition for both RT [$F(2, 34) = 5.32$, $p = .0097$] and accuracy [$F(2, 34) = 10.12$, $p = .0004$]. Post hoc analyses for RT revealed an overall RVF match (LH) advantage with no significant difference among conditions for separate LVF and RVF match targets (see Figure 45). When each condition was compared across the VF match

variable, LARU did not show VF effects. However LURA (p = .0001) and DU (p = .0093) both exhibited faster RTs for RVF than LVF match targets. A significant contrast analysis indicated that the RVF advantage was significantly larger for LURA than DU. Post hoc analyses for accuracy yielded a slightly different pattern of results than was found for RT (see Figure 46). Specifically, for LVF match (RH) trials condition LARU showed significantly greater accuracy than LURA, and also approached significance for greater accuracy than DU (p = .052).

Figure 45

Interaction between VF match and condition for reaction time for VF match trials only

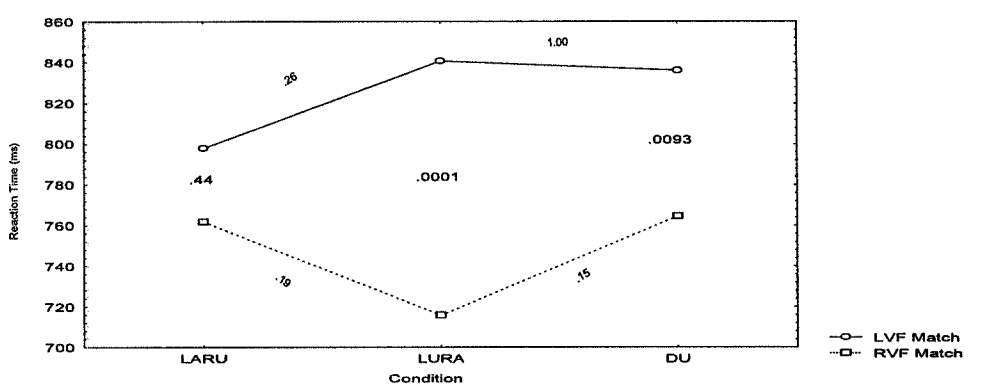
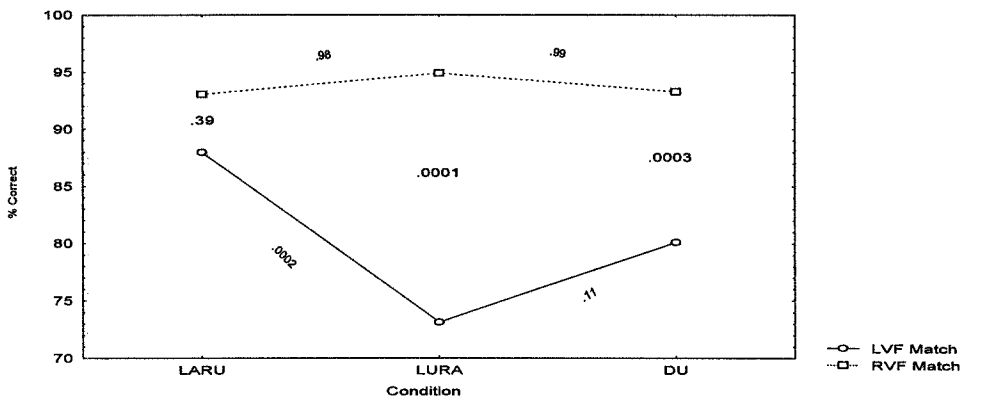


Figure 46

Interaction between VF match and condition for accuracy for VF match trials only



Overall, the RVF match (LH) trials were responded to more quickly and more accurately than LVF match, and responses for the LARU (RH primed) condition were more accurate than LURA and DU, which did not differ from one another. Condition DU (no priming for both hemispheres) simulates a control condition since neither hemisphere is primed. Consistent with this idea, a RVF match advantage was largest for LURA (LH primed) and smallest for LARU (RH primed), with DU performance falling in between these conditions, possibly due to LH superiority for language. For LARU there was no VF match advantage, presumably because RH priming abolished the RVF (LH) match advantage, but was not sufficient to produce a LVF (RH) match advantage. For LURA, there was an increased RVF advantage since priming occurs in the RVF (LH). These results support an overall LH superiority for this task, although priming effects appear to occur in both hemispheres. Figure 47 illustrates ERP components across all sites for identical versus non-identical bilateral trials in Experiment 3.

Five ERP components were analyzed as described for Experiments 1 and 2, except a P400 emerged instead of an N400, different latency windows were used, and there were no non-word stimuli. In addition, there was no visual field variable due to bilateral presentation of T1. Instead, the condition variable (as defined for the behavioral analyses) was included. As in Experiment 2, the epoch recorded during T1 (not T2) was analyzed. The following analyses were conducted for the N90 (65-115 ms), N275 (250-300 ms for posterior sites), N295 (270-320 ms for anterior sites), P400 (350-450 ms), and LPC (450-600 ms).

ERP Data

N90 (65-115 ms): Midline Sites

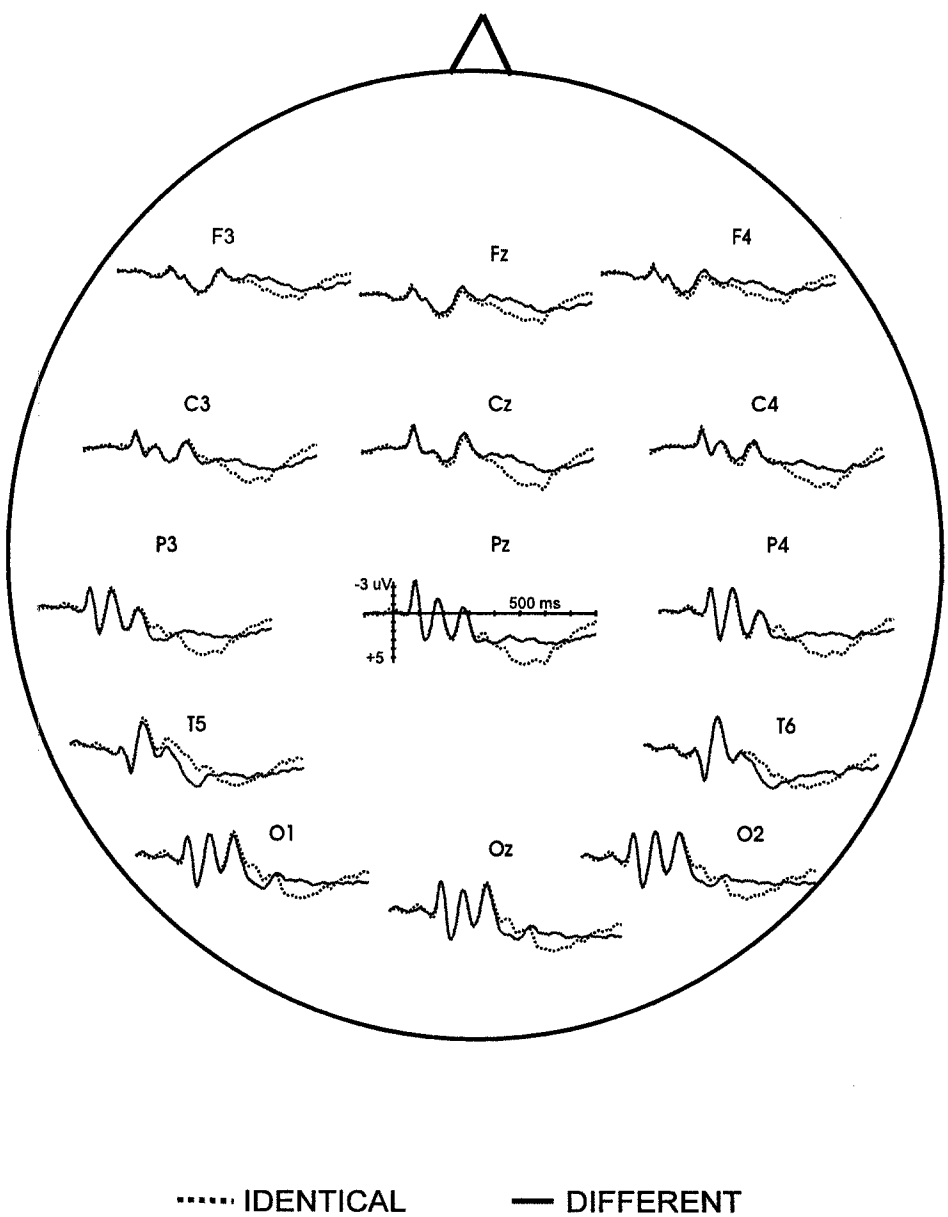
A 5 (condition) x 4 (site) ANOVA was conducted and resulted in a significant main effect of site [$F(3, 51) = 4.51$, $p = .0070$], where N90 amplitudes at Cz ($M = -1.57$ uV), Pz ($M = -1.71$ uV), and Oz ($M = -1.38$ uV) were all significantly larger than Fz ($M = -0.34$ uV), but were not significantly different from one another as shown by post hoc analyses. These results are consistent with early visual processing, whereby the posterior sites would show the largest amplitudes.

N90 (65-115 ms): Lateral Sites

A 5 (condition) x 5 (site) x 2 (hemisphere) ANOVA again resulted in a significant main effect of site [$F(4, 68) = 13.44$, $p < .0001$], where N90 amplitudes were largest at frontal ($M = - .096$ uV), central ($M = -0.99$ uV) and

Figure 47

ERPs across all sites for identical versus non-identical bilateral stimuli in Experiment 3



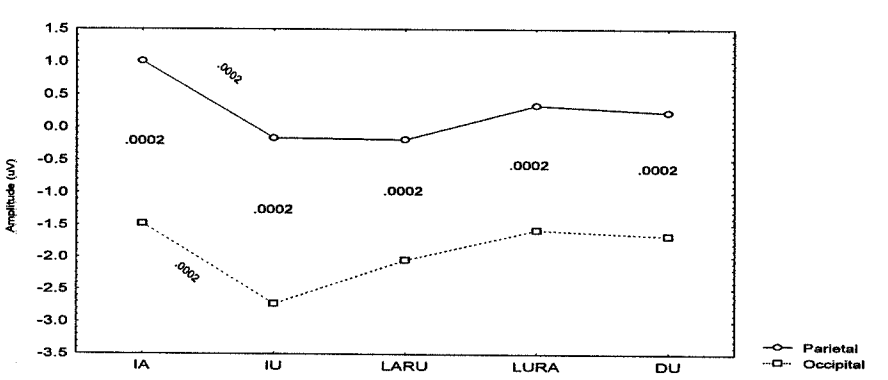
temporal (M = - 1.02 uV) sites. Post hoc results indicated that only N90 amplitudes at temporal sites were significantly larger than all other sites

N275 (250-300 ms): Posterior Midline Sites

A 5 (condition) x 2 (site) ANOVA revealed a significant interaction between condition and site [F(4, 68) = 3.75, p = .0082], where N275 amplitudes for Oz were significantly larger than for Pz (see Figure 48). However, post hoc analyses did not reveal the source of the significant interaction, so a contrast analysis was performed to compare differences for site by grouping conditions IA and IU against LARU, LURA, and DU (as a group). This analysis showed that identical bilateral stimuli conditions resulted in a larger discrepancy between parietal and occipital N275 amplitudes (occipital larger) than for different bilateral stimuli conditions (p = .0060). These findings suggest more sensory processing at the occipital site since the difference is larger for identical versus different stimuli in the visual fields, rather than a difference based on semantic association.

Figure 48

Interaction of condition by site for N275 amplitudes at posterior midline sites



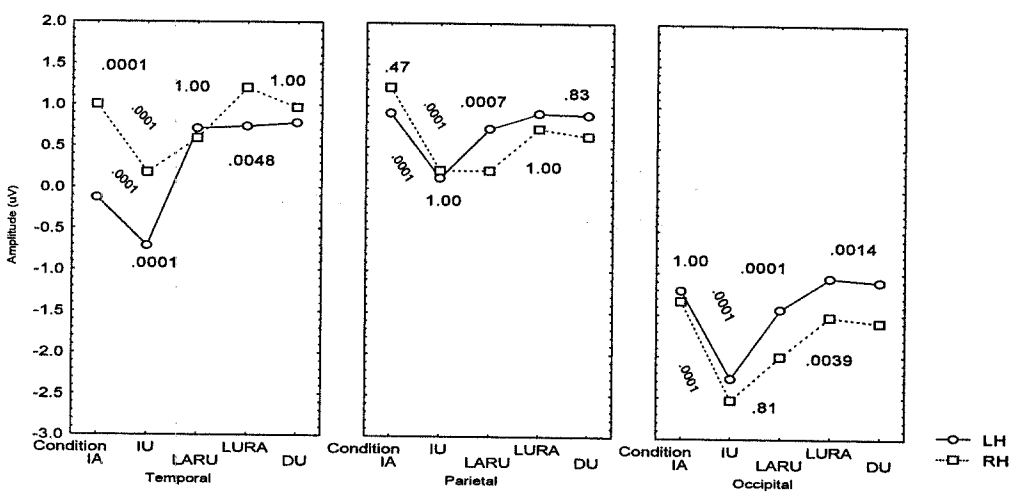
N275 (250-300 ms): Posterior Lateral Sites

A 5 (condition) x 3 (site) x 2 (hemisphere) ANOVA revealed a significant main effect of site [$F(2, 34) = 9.58$, $p = .0005$], where occipital ($M = -1.60$ uV) amplitudes were significantly larger than temporal ($M = 0.53$ uV) and parietal ($M = 0.66$ uV) sites. Similar to midline analyses, there was a significant interaction between condition and site [$F(8, 136) = 5.52$, $p < .0001$]. There were also significant interactions for condition x hemisphere [$F(4, 68) = 4.97$, $p = .0014$] and site x hemisphere [$F(2, 34) = 6.76$, $p = .0034$]. All of these interactions are contained within the interaction for condition x site x hemisphere which approached significance [$F(8, 136) = 2.49$, $p = .015$] (see Figure 49). Post hoc analyses revealed larger N275 amplitudes for condition IU as compared to condition IA at all posterior sites (see Figure 49). This finding is similar to N400 results where unprimed conditions yield the largest amplitudes. An interaction contrast analysis was conducted to further examine identical versus non-identical stimuli x hemisphere x site, and this approached significance [$F(2, 34) = 3.25$, $p = .051$]. Therefore, separate contrast analyses were used to look at each site individually rather than collectively. Results for temporal sites indicate that the hemispheric difference between identical conditions is significantly larger than for non-identical conditions, with the LH showing more negative amplitudes ($p = .021$). The opposite was true for the remaining sites, where hemispheric differences were significantly larger for non-identical conditions as compared to identical conditions, with the RH showing more negative amplitudes for parietal

(p = .019), and occipital (p = .006) sites. The different pattern occurring over temporal sites and the difference between IA and IU conditions for all posterior sites suggest that the N275 may reflect more cognitive than sensory processes.

Figure 49

Interaction of condition x site x hemisphere for N275 amplitudes at posterior lateral sites



N295 (270-320 ms): Anterior Midline Sites

A 5 (condition) x 2 (site) ANOVA yielded only insignificant findings.

N295 (270-320 ms): Anterior Lateral Sites

A 5 (condition) x 2 (site) x 2 (hemisphere) ANOVA also yielded no significant findings.

P400 (350-450 ms): Midline Sites

A 5 (condition) x 4 (site) ANOVA revealed a significant main effect of site [F(3, 51) = 6.09, p = .0013], where P400 amplitudes were significantly larger for

parietal (M = 3.21 uV) and occipital (M = 2.49 uV) sites as compared to frontal (M = .78 uV) and central (M = 1.03 uV) sites. There was also a significant interaction between condition and site [F(12, 204) = 4.03, p < .0001] which also occurred for lateral sites, and is discussed in more detail below.

P400 (350-450 ms): Lateral Sites

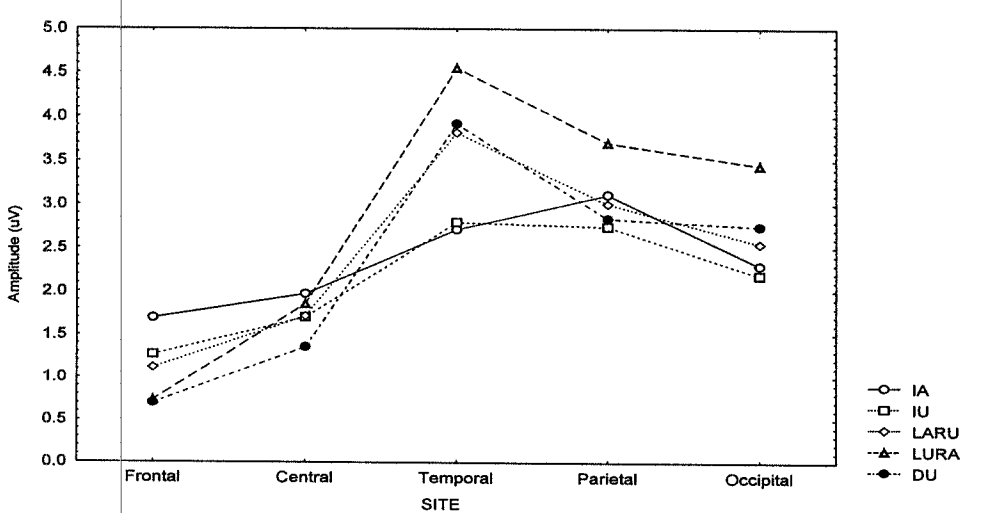
A 5 (condition) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of site [F(4, 68) = 4.11, p = .0048], where P400 amplitudes for temporal (M = 3.56 uV), parietal (M = 3.08 uV), and occipital (M = 2.64 uV) were significantly larger than for frontal (M = 1.10 uV) and central (M = 1.72 uV) sites, except the difference between central and temporal sites only approached significance (p = .075). As found above for midline sites, there was a significant interaction between condition and site [F(16, 272) = 6.59, p < .0001]. Three different patterns emerged for: (a) frontal and central, (b) temporal, and (c) parietal and occipital sites across conditions (see Figure 50). For frontal and central sites, there were no differences in P400 amplitudes across the five conditions. A contrast analysis examined whether amplitudes for only temporal sites differed by identical versus different stimuli. A significant redundancy effect was found (p = .016), whereby different bilateral conditions elicited larger P400 amplitudes than identical conditions. Parietal and occipital sites were examined together via a contrast analysis to determine whether P400 amplitudes for condition LURA (LH primed) were significantly larger than the remaining conditions. Results of this contrast showed that P400 amplitudes were larger for

LURA than for all other conditions, and this finding approached significance (p = .051). It appears as if LH priming has a tendency to elicit larger P400 amplitudes for posterior (language processing) regions.

The P400 is an unexpected component that occurred instead of the N400, possibly due to the bilateral nature of the stimuli. According to contrast analyses conducted for temporal sites, a significant redundancy effect (same stimuli in both VFs) occurred that does not fit with some interpretations of late positivities. Specifically, redundant conditions resulted in significantly smaller P400 amplitudes. If ease of processing was indicated (as it generally is for LPCs), then one would expect amplitudes to be larger for redundant stimuli. In addition, posterior sites approached significance for LH priming effects, suggesting that posterior regions are more sensitive to associative priming in the RVF.

Figure 50

Interaction between condition and site for P400 amplitudes at lateral sites



LPC (450-600 ms): Midline Sites

A 5 (condition) x 4 (site) ANOVA revealed a significant main effect of condition [$F(4, 68) = 10.24$, $p < .0001$], where LPC amplitudes were largest for IA ($M = 4.12$ uV) and IU ($M = 3.96$ uV), which did not significantly differ from one another, but did significantly differ from conditions LARU ($M = 2.04$ uV), LURA ($M = 2.17$ uV), and DU ($M = 2.00$ uV), which also did not differ from one another. There was also a significant main effect of site [$F(3, 51) = 4.70$, $p = .0056$], where LPC amplitudes appeared larger for parietal ($M = 3.96$ uV) and occipital ($M = 3.34$ uV) sites as compared to frontal ($M = 1.73$ uV) and central ($M = 2.41$ uV) sites. However, only frontal and parietal sites differed significantly from one another.

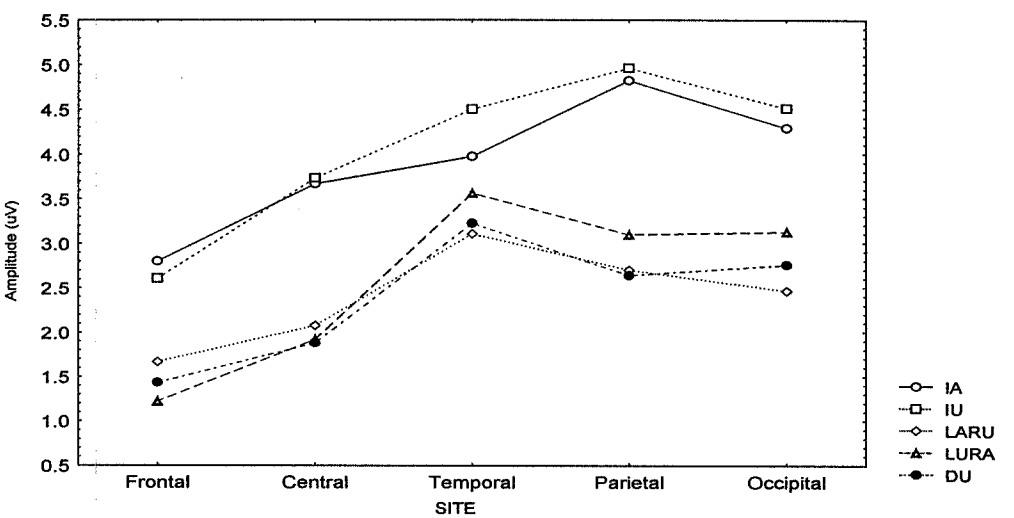
LPC (450-600 ms): Lateral Sites

A 5 (condition) x 5 (site) x 2 (hemisphere) ANOVA yielded a significant main effect of condition [$F(4, 68) = 6.66$, $p = .0001$] consistent with midline analyses, where LPC amplitudes were largest for IA ($M = 3.91$ uV) and IU ($M = 4.06$ uV), which again did not significantly differ from one another, but did significantly differ from conditions LARU ($M = 2.40$ uV), LURA ($M = 2.58$ uV), and DU ($M = 2.39$ uV), which also did not differ from one another. A significant interaction effect was found between condition and site [$F(16, 272) = 2.36$, $p = .0027$]. There was a strong LPC component for redundant (IA and IU) conditions for all sites except temporal (see Figure 51), which is consistent with the interpretation that a large LPC indicates ease of processing. At temporal sites,

IA, IU and LURA (LH priming) did not differ from one another according to post hoc analyses, and these should be the easiest conditions for participants, while IA and IU did significantly differ from LARU and DU. However, LARU, LURA, and DU conditions did not significantly differ from one another, indicating different stimuli in the VFs are likely the most difficult to process in general.

Figure 51

Interaction between condition and site for LPC amplitudes at lateral sites



Overall, LPC amplitudes were most pronounced for redundant stimuli as compared to different stimuli in the VFs. However, for temporal sites, condition LURA (LH priming) also resulted in larger LPC amplitudes that did not differ from redundant conditions, whereas condition LURA did significantly differ from redundant conditions for all other sites. Perhaps word processing over the temporal region is more sensitive to LH priming.

CHAPTER IV

DISCUSSION

The three experiments were designed to investigate both behavioral and neurophysiological effects of semantic priming and orthographic manipulations of non-words within both lexical decision and delayed matching tasks. Experiment 1 provided basic results of primed and unprimed lexical decision-making with unilateral presentations of target stimuli. In addition to these effects, Experiment 2 also addressed component overlap between the later ERP components N400 and LPC. This was achieved by using a delayed matching response with unilateral target presentations (instead of immediate lexical decision) to reduce the component overlap that was found in Experiment 1. Experiment 3 explored the effects of bilateral rather than unilateral target presentations by using only word stimuli in the same delayed matching task used in Experiment 2. Lastly, hemispheric and VF effects were also analyzed for all experiments to further examine how the hemispheres process language. A summary of findings from specific research questions proposed earlier follows.

Word and Non-Word Effects

Previous research shows a LH advantage for lexical decision when the target is a word over when it is a non-word (e.g., Chiarello, 1988; Mohr, et al., 1994). This finding was confirmed not only in Experiment 1 which used a lexical

decision task, but also for Experiment 2 which used a delayed matching task, where responses to RVF (LH) stimuli in both experimental paradigms were both faster and more accurate than to LVF (RH) stimuli. These findings are consistent with LH specialization for these language tasks. Furthermore, there was an overall advantage for words over non-words. Regardless of VF of presentation for both the word and non-word trials in the delayed matching paradigm, responses to word targets (T2) were faster and more accurate when they matched a preceding target (T1) than when they did not match, while the opposite pattern emerged for non-words. It seems to be easier to determine when there is a match for word targets (i.e., T1 = T2) because they already exist in the lexicon. However, when non-word targets match, there is no lexical representation to facilitate a match decision. Determining whether unfamiliar letter strings (i.e., non-words) match requires additional processing since they are not represented in the lexicon, while word stimuli have an advantage of being encoded as a perceptual unit (Chiarello, 1988). However this advantage disappears when word targets are mismatched. Perhaps it is more difficult and/or time consuming to search the lexicon for two different words than it is to do letter-by-letter comparisons of non-words. In this way, the no match condition actually becomes an advantage for non-words because the difference would be encountered at the first incongruity between letters of T1 and T2. It follows that this type of letter-by-letter processing would then be a disadvantage when the

letter strings were identical because comparisons of every letter would be necessary, rather than using an entire percept.

The ERP findings disclose word/non-word effects for both the N400 and LPC. However, they also tend to involve priming and pronounceability effects, which will be discussed in the following sections.

Association Effects

There is considerable behavioral evidence that both cerebral hemispheres exhibit semantic priming effects, although there appears to be qualitative differences in the semantic networks of each hemisphere (Chiarello, 1988; Chiarello, et al., 1990; Chiarello & Richards, 1992; Young & Ellis, 1985; Zaidel & Peters, 1981). For example, associative priming leads to faster and more accurate responses as compared to unrelated priming for lexical decision for both hemispheres (Clarke & Zaidel, 1994; Neely, 1977; Zaidel et al., 1990), while categorical priming reportedly results in only RH facilitation effects (Chiarello, et al., 1990; Chiarello & Richards, 1992). Consideration of prime word location is important, as the RH advantage for categorical priming disappears with central rather than lateralized prime words (Chiarello et al., 1990). Both behavioral and ERP results from this study provide findings that illustrate the facilitative effects of semantic priming for both hemispheres, consistent with previous findings (Clarke & Zaidel, 1994; Neely, 1977; Zaidel et. al., 1990). The expected advantage for word trials with semantic priming was found for accuracy, regardless of VF, in Experiments 1 and 2. However, in Experiment 1, unprimed trials showed a RVF

advantage for accuracy, indicating that the LH is better than the RH at lexical decision without priming. When the RH is aided by semantic priming, performance improves to the level of the LH. There was also an overall RVF advantage for both primed and unprimed trials, supporting LH dominance for language processing. Findings from Experiment 3 (T1 was presented bilaterally) did not reveal any overall association effects. Instead, a redundancy effect emerged where identical T1 stimuli showed an advantage over non-identical T1 stimuli, regardless of whether word targets were associated or unassociated to the prime. However, when one considers non-identical T1 trials (LVF T1 ≠ RVF T1) in which either the LVF or the RVF T1 stimulus matches the subsequent target (T2), a RVF match (LH) advantage emerged for condition LURA (LH primed) and DU (no priming), but not for LARU (RH primed). These findings support LH language dominance since a RVF match advantage occurred even in the unprimed condition. However, both hemispheres appear to be sensitive to priming effects since LH priming (LURA) increased the RVF advantage, and RH priming (LARU) eliminated the RVF advantage.

The earliest evidence for an ERP association effect was for the posterior P230/N290 component (210-300 ms) in Experiment 1, where parietal amplitudes were more negative for unprimed than for primed conditions, while there was no such difference at temporal and occipital sites. This pair of components appears to be an indicator of an initial stage of cognitive processing for semantic relatedness. This effect was absent in Experiment 2, possibly because this task

is less difficult and subsequently requires a shallower level of processing. Even though Experiment 3 also involved a matching response, an association effect emerged for the posterior N275 component (250-300 ms). Specifically, for all posterior sites, identical/unassociated T1 stimuli (IU) evoked larger N275 amplitudes than did identical/associated T1 stimuli (IA). These findings may also indicate the presence of early cognitive processing based on semantic association.

The N400 and LPC are of particular interest in terms of association effects, since the N400 is typically evoked for unprimed (as compared to primed) conditions and to pronounceable non-words (PNWs) [but not to non-pronounceable non-words (NPNWs)], while the LPC will again indicate ease of processing. Results from both Experiments 1 and 2 are consistent with previous research (Kutas & Hillyard, 1984; Holcomb, 1993), since there was an expected significant main effect of association where unassociated prime-target pairs elicited the largest N400. However, this association effect for the N400 did not interact with visual field or hemisphere in Experiments 1 and 2. Although there was no N400 in Experiment 3, the N275 component showed an association effect for identical (T1) stimuli, whereby larger N275 amplitudes occurred in response to IU as compared to IA conditions. The N275 could be interpreted as being an early N400 in this task since amplitudes were larger in response to unassociated stimuli, as is typically found with the N400.

LPC amplitudes for Experiments 1 and 2 also correlate with behavioral findings since they tended to be larger for the primed condition which facilitated behavioral performance, again indicating ease of processing. The LPC component showed an advantage (larger positive amplitudes) of association that was larger over the LH as compared to the RH for Experiment 2, while this hemispheric effect was absent in Experiment 1. LPC amplitudes for Experiment 3 were most pronounced for identical (T1) stimuli than for different (T1) stimuli, reflecting ease of processing resulting from redundancy rather than association effects.

Overall, these results replicate previous studies describing the N400 as an indicator of semantic incongruity (Kutas and Hillyard, 1984), and the LPC as an indicator of processing ease (Halgren and Smith, 1987). Although behavioral data support the notion that both hemispheres are susceptible to priming, there was limited ERP evidence for hemispheric effects of association. Perhaps this finding can be attributed to the occurrence of simultaneous processing within both hemispheres, resulting in an overall activation. In this case, independent processing may be similar enough that ERP differences cannot be distinguished. Lastly, the discovery of earlier ERP association effects (200-300ms latency range) was an unexpected and novel finding for these tasks, and hence may be related to lateralization of target stimuli since this has been the first attempt to examine ERP correlates of lateralized semantic priming. More ERP research needs to be conducted with lateralized stimuli to further investigate this effect.

Pronounceability Effects

One of the main hemispheric differences in processing non-words is the ability of the LH to use grapheme-to-phoneme conversion, while the RH lacks this ability and apparently processes non-words orthographically (without phonological translation) (Cohen & Freeman, 1978; Krueger, 1975; Zaidel & Peters, 1981). Both behavioral and ERP findings for Experiments 1 and 2 (Experiment 3 did not include non-words) show significant effects of pronounceability for non-word trials in addition to laterality effects. For Experiment 1, NPNWs resulted in faster and more accurate performance than PNWs. These findings support a letter-by-letter processing approach to word and non-word reading, since violations in the orthographic structure of NPNWs are encountered before fully processing the stimulus, thus facilitating lexical decision-making. On the other hand, PNWs do not violate orthographic structure, and subsequently would require further processing which would slow lexical decision-making. In addition, opportunity for erroneous processing increases as the stimulus becomes more word-like. There was also an overall RVF (LH) advantage for both RT and accuracy measures, but there were no interactions of pronounceability with VF. These results provide support for LH specialization for detecting non-words, regardless of pronounceability. Findings from Experiment 2 showed the opposite effect, whereby more accurate performance was found for PNWs. This discrepancy may be due to the change in task demands from lexical decision to delayed matching. Phonetic encoding of

the PNWs probably makes them easier to remember which may facilitate accurate matching of PNW targets. But, if the LH has grapheme-to-phoneme capability and the RH does not (Zaidel and Peters, 1981; Zaidel, 1985) why is there no interaction of pronounceability with VF? Perhaps, interhemispheric transfer occurs during the extra interval between T1 and T2 presentations of the delayed matching task (which is absent for Experiment 1), allowing for a balance between hemispheres to be established more readily. The addition of the match/no match variable resulted in no effect of match for PNWs, but more accurate and faster responses for NPNWs in the no match condition, as compared to the match condition. These results provide additional support for grapheme-to-phoneme processing of PNWs because this type of processing would occur whether or not the targets matched (resulting in no effect of match), and for letter-by-letter processing of NPNWs as discussed above for Experiment 1.

The only variable in all of the experiments that produced clear laterality effects for cognitive ERP measures was pronounceability. Specifically, N400 amplitudes were larger in Experiment 1 for PNW than for NPNW stimuli presented to the RVF (LH). Left VF (RH) presentation did not distinguish non-word types (see Figure 22). These findings provide strong support for LH capability of grapheme-to-phoneme processing and a lack of this ability for the RH, which is weakly supported by the behavioral data that show an overall RVF (LH) advantage for both non-word types, (rather than PNWs only). Analyses of

the N400 in Experiment 2 also support the notion of LH specialization for grapheme-to-phoneme processing. Specifically, LVF (RH) presentations showed no difference in N400 amplitudes for pronounceability over the RH, while both RVF and LVF presentations showed larger N400 amplitudes, as expected, for PNW than for NPNW trials over the LH (see Figure 39). These findings do not parallel the behavioral results in which there was no lateralization of non-word effects. However, behavioral measures in Experiment 2 reflect performance after the presentation of T2, while ERPs were analyzed only for T1, which may explain this discrepancy. LPC amplitudes for both experiments were larger in response to NPNWs than to PNWs, which agrees with behavioral results from Experiment 1, indicating that NPNWs are easier to process for lexical decision. However, behavioral findings from Experiment 2 only partially support the notion that NPNWs are easier to process, since the NPNW advantage was only found when T1 did not match T2. Again, ERPs were only analyzed for T1, so this correlation is weak at best.

In sum, it appears that the N400 is more sensitive than the LPC to lateralized pronounceability effects, since significant results were found only for the N400. There was a fairly robust effect of pronounceability and VF, where larger N400 amplitudes occurred in response to PNWs for RVF presentation, and there was no effect of pronounceability for LVF presentation, which occurred despite changing task demands in Experiments 1 and 2. Although these findings do not correlate with behavioral measures from the current study, they do fit

nicely with previous research regarding RH processing of non-words (Cohen & Freeman, 1978; Krueger, 1975; Zaidel & Peters, 1981), and with predictions for this study stating that the difference in N400 amplitudes between PNW and NPNW stimuli would be larger over the LH since the LH is more susceptible to phonological effects.

Early ERPs

The N90 is an exogenous ERP component thought to reflect early stages of sensory processing (visual in this study). Most early sensory potentials (approximately 10-100 ms) are not considered to reflect cognitive processing in general (Coles, Gratton, and Fabiani, 1990; Kutas and Van Petten, 1994). All three experiments in this study showed the largest N90 amplitudes over posterior sites, consistent with early visual processing that is expected to occur over occipital regions. Surprising results were found for both Experiments 1 and 2, where target stimuli were presented unilaterally to one VF. Specifically, a paradoxical effect was found whereby indirect VF-hemisphere presentations produced the larger N90 amplitudes over both hemispheres than did direct VF-hemisphere presentations. This effect was absent in Experiment 3 where targets were presented bilaterally, apparently since both hemispheres are receiving visual stimuli simultaneously. It seems as though this paradoxical effect may have been caused by dipole orientation (generators directing electrical activity toward the opposite hemisphere), rather than reflecting the actual location of electrical activity over the scalp. However, for Experiments 1 and 2, earlier N90

latencies occurred for direct VF-hemisphere presentations than for indirect VF-hemisphere presentations, arguing against the dipole orientation explanation. Therefore, further investigation of this effect is necessary to address this discrepancy.

Event-related potentials appearing at approximately 100-200 ms fall between exogenous and endogenous potentials and are believed to reflect the process of selective attention, typically resulting in larger amplitudes for the attended conditions (Coles, Gratton, and Fabiani, 1990). For example, stimuli presented to the LVF should elicit larger amplitudes over the RH and vice versa, due to direct presentation of the stimuli. Analyses of midline sites for Experiments 1 and 2 did not show any significant VF effects as expected, but amplitudes over lateral sites did show such hemispheric effects, which were also dependent upon component polarity. Anterior lateral N140 amplitudes for Experiment 1 and all lateral P130/N190 amplitudes for Experiment 2 showed larger negative amplitudes for direct than for indirect VF-hemisphere presentations. Overall, direct VF-hemisphere presentations usually produced larger negative amplitudes for components in the 100-200 ms latency range. These findings reflect an advantage for presentations of stimuli via direct over indirect anatomical pathways.

What is the LPC?

The LPC (or P300) typically is most pronounced over the central and parietal sites, and is defined by several functions, including ease of processing,

decision-making, memory updating, cognitive closure, and processing of oddball (less frequent) stimuli. The peak latency of this component varies according to task difficulty, so that easier tasks such as a simple auditory oddball paradigm elicit a much earlier LPC (around 300 ms) than more difficult tasks such as primed lexical decision (approximately 600 ms). For all experiments in this study, using the LPC as an indicator of processing ease was quite useful for correlating ERP and behavioral findings. For example, associated word and NPNW conditions facilitated behavioral performance and also elicited the largest LPC amplitudes in Experiment 1. LPC amplitudes were successfully attenuated in both Experiments 2 and 3 by delaying the decision-making process in order to decrease component overlap with the N400. However, for Experiment 3, an unexpected component (P400) occurred instead of the N400 in the 350-450 ms latency range. This appears to be an early LPC for this task. The main task difference in Experiment 3 is bilateral target (T1) presentation. As mentioned previously, it seems the most efficient approach for this task is to use redundancy rather than associative priming to facilitate performance. If so, then perhaps the P400 is tuned to detecting redundancy rather than semantic priming. Another important factor to mention is the disproportionate ratio (2:4) of identical stimuli to non-identical stimuli. Therefore, the P400 may reflect a simple oddball paradigm effect, where the less frequent (identical T1s) stimuli produce larger positive amplitudes, especially since the P400 (350-450 ms) is occurring earlier than the LPC (450-600 ms) where higher cognitive demands increase the latency.

There were some surprising findings for the LPC when considering direct and indirect VF-hemisphere conditions. Although RVF (direct) presentations resulted in larger LPC amplitudes than LVF (indirect) presentations over the LH as predicted, RVF (indirect) presentations over the RH unexpectedly elicited the largest LPC amplitudes in Experiment 1. It was also surprising to find various VF-hemisphere effects for the LPC (some paradoxical) that were dependent upon site in Experiment 2, however most effects were quite small (< 1 uV). For example, LPC amplitudes were always larger for indirect VF-hemisphere than for direct VF-hemisphere conditions (paradoxical effect) over temporal sites, while parietal sites showed a paradoxical VF-hemisphere effect over the RH for word targets and over the LH for non-words, indicating a condition-specific effect.

Overall, the LPC was a very good indicator of processing ease across experiments. Some paradoxical effects, including different patterns according to electrode site, indicate there may be more than one generator for the LPC found in this study.

What is the N400?

The N400 is an endogenous ERP component appearing approximately 350-400 ms post-stimulus, with a negative-going peak. The N400 typically occurs in response to semantic incongruities encountered when reading sentences (Kutas & Hillyard, 1984) or even word pairs (Holcomb & Neville, 1990; Kutas & Van Petten, 1994). Results from Experiments 1 and 2 replicate these findings. It was predicted that N400 amplitudes should be reduced more

significantly over the RH since previous research suggests that the RH is more susceptible to priming effects. However, there were no hemispheric differences in N400 amplitude based on association effects for Experiments 1 and 2. The N400 is also commonly elicited by PNWs, but not by NPNWs (Bentin, 1987; Holcomb, 1988; Smith & Halgren, 1987), possibly due to phonological processing of PNWs (i.e., incongruous but word-like) since they resemble actual words. Thus, the N400 is not simply evoked by any kind of incongruity, but rather by those that follow certain linguistic rules. More controlled (rather than automatic) processing is necessary to make such distinctions, so the N400 is not thought to be merely a mismatch detector. When considering these interpretations of the N400, findings in Experiment 1 are puzzling since N400 amplitudes of similar magnitude occurred not only for unassociated words and PNWs, but also for NPNWs. That is, all three target conditions (UW, PNW, and NPNW) produced equivalent N400s that, in turn, were much larger than for associated words. Perhaps these three target conditions are in some sense all unrelated to the prime word, since the N400 is thought to occur in response to incongruent or unrelated semantic relationships. In this manner, associated words is the only true primed or congruent condition. While the delayed matching task reduced component overlap, which allowed for larger N400 amplitudes that were greatest for the UW and PNW conditions (as predicted), there was not a significant difference between N400 amplitudes for PNWs and NPNWs in Experiment 2. It seems that reduced processing demands from matching stimuli in Experiment 2

(instead of lexical decision) may have prevented more pronounced N400 effects since this component is sensitive to depth of processing. It was also surprising that there would be no N400 in Experiment 3. Due to the overwhelming redundancy effects found in Experiment 3, it appears that automatic processing of T1 stimuli (identical versus different in the VFs) is the most efficient way to perform the task, rather than deeper, controlled processing (typical for lexical decision) that is necessary to elicit an N400.

The strongest reported N400 effects have been found in response to an incongruous word located within the context of a sentence (e.g., Kutas & Hillyard, 1984). Therefore, it seems that shallower task demands altered or even eliminated the appearance of the N400 in this study, such as the surprising finding that the N400 can be produced by non-pronounceable non-words. However, when this effect is examined more closely, larger N400 amplitudes did occur in response to PNWs as compared to NPNWs over the LH. Perhaps this unexpected occurrence of the N400 for NPNWs can be explained by the use of lateralized target words in this study, which increased RH involvement, where there is no processing distinction between PNWs and NPNWs.

Component Overlap

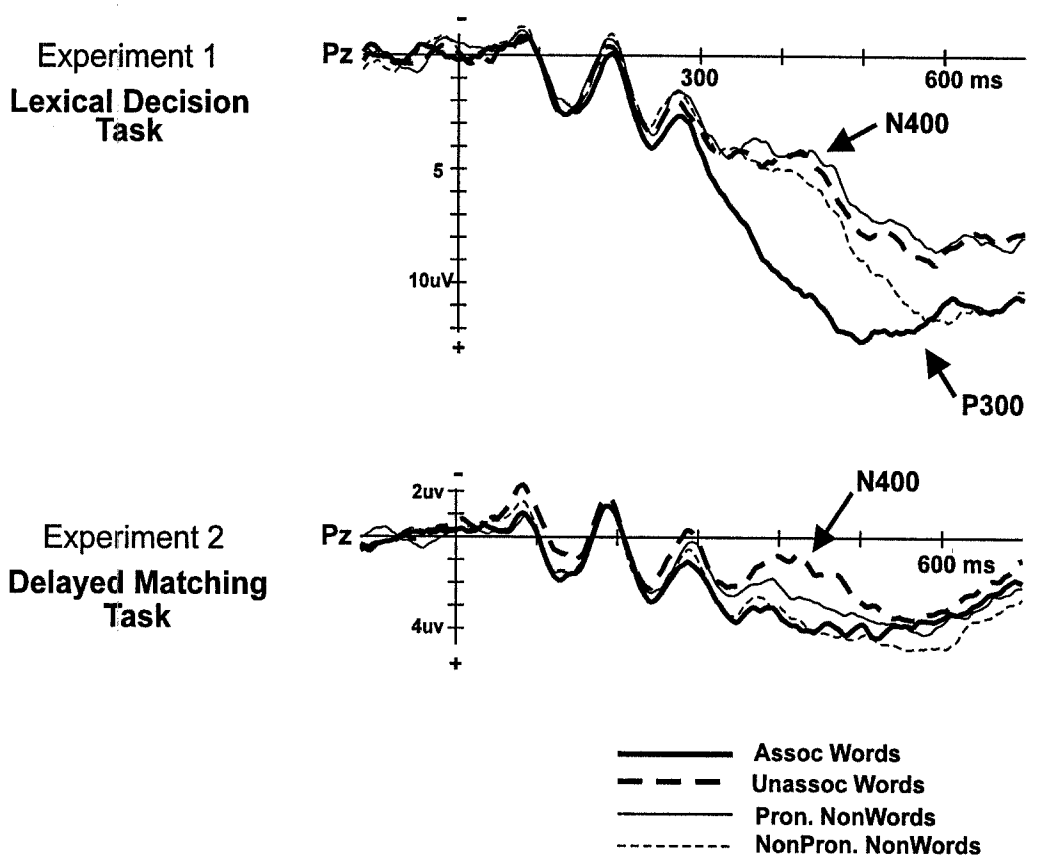
Recall, component overlap occurs when one ERP component affects another's amplitude if they occur too closely in time. The purpose of using delayed matching for Experiment 2 was to attempt to reduce component overlap between the LPC and N400. The lexical decision task results in immediate

decision making, which has been shown to consistently produce large LPC amplitudes that can cause attenuation of N400 amplitudes, as confirmed by Experiment 1. Although task demands in Experiment 2 successfully reduced the LPC dramatically, the pattern of findings among the four types of target stimuli (AW, UW, PNW, NPNW) for both the LPC and N400 were altered (see Figure 52). As mentioned above, findings from Experiment 1 revealed equivalent N400 amplitudes for UW, PNW and NPNW conditions, which were all larger in amplitude than the AW condition. In this case only associated words are related to the preceding prime. For Experiment 2, a reliable N400 was only found for the UW condition. It appears that task demands for delayed matching may minimize semantic priming effects, so only the condition most sensitive to eliciting the N400 (UW) produces this component. There was an absence of the N400 in Experiment 3, which was discussed in the previous section.

Overall, Experiment 2 resulted in larger N400 amplitudes by reducing LPC amplitudes. However, changing task demands also affected which conditions elicited both the LPC and N400. Perhaps shallower processing in Experiment 2 caused this change, similar to that found by Bentin, et al. (1993). Therefore, it is important to consider the level of processing each task requires if using this manipulation to control component overlap.

Figure 52

Comparison of LPC and N400 components in Experiments 1 and 2 at site Pz, illustrating component overlap



Hemispheric Effects

Left hemisphere superiority for most language processing has been well established, while the role of the RH is not as clearly defined. It is also uncertain as to how much the hemispheres share information, or hinder/aid one another when processing language stimuli. Both behavioral and ERP data from this

study confirm previous research as well as provide novel findings that help increase our knowledge about these issues.

It was not surprising to find an overall RVF (LH) advantage for behavioral data from Experiments 1 and 2, and a RVF match advantage (T1 presented to the RVF matched the centrally-presented T2, while the LVF T1 did not match T2) in Experiment 3. However, the only interaction of association with VF occurred in Experiment 1, where a RVF (LH) advantage was found for word trials with unassociated primes, indicating that the RH has more difficulty with lexical decision when the related prime is not used. Additional information regarding interhemispheric cooperation and RH processing was found from Experiment 3, where bilateral target stimuli were used. When all trials were analyzed together, only a redundancy effect emerged (identical T1 stimuli facilitated performance). However, when only those trials with different stimuli in the VFs were analyzed, various priming effects arose. A RVF match advantage was largest for LURA (LH primed) and smallest for LARU (RH primed), with condition DU (no priming) falling in between. Therefore, even though RH priming is not strong enough to cause a LVF match advantage, it does seem to affect LH performance by eliminating the RVF match advantage. These data support the idea that priming can occur in both hemispheres. Furthermore, interhemispheric cooperation is not implicated, since priming in one VF only seems to benefit the hemisphere receiving direct input from that VF.

N400 amplitudes were usually larger for direct VF-hemisphere presentations than indirect VF-hemisphere presentations for both hemispheres, providing evidence for the sensitivity of both the LH and the RH to direct hemispheric processing. Although several studies show slightly larger N400 amplitudes over the RH (Kutas & Hillyard, 1984; Kutas & Van Petten, 1990, 1994; Pritchard, Shappell, & Brandt, 1991), this effect is small and inconsistent with other studies including the current one. Lateralization of the N400 seems to be susceptible to the VF of presentation, and to tasks requiring a deeper level of processing, such as lexical decision, since the N400 reflects deeper cognitive processing (i.e., semantic incongruity). For example, N400 amplitudes were larger over the LH than the RH for word stimuli in Experiment 1, while this effect was not found in Experiment 2. On the other hand, lateralization of the LPC, which reflects ease of processing, may be affected more strongly by tasks requiring a shallower level of processing, such as delayed matching. For example, LPC amplitudes in Experiment 2 were larger for associated than unassociated word trials over the LH, (no associative differences were found over the RH), while there were no hemispheric effects for word trials in Experiment 1.

A closer look at the N400 in Experiment 1 revealed lateralization effects for non-word stimuli, whereby PNWs elicited significantly larger N400 amplitudes than NPNWs for RVF (LH) presentations, while no effect of pronounceability was found for LVF (RH) presentations (see Figure 28). These data support RH

inability to use grapheme-to-phoneme translation for non-words, since both types of non-words are processed as if they violated orthography. Experiment 2 findings are consistent with these results since significantly larger N400 amplitudes to PNWs than to NPNWs were recorded over the LH for both LVF and RVF presentations, while a similar effect was found over the RH for only RVF (LH) presentations (see Figure 39). In other words, the difference in N400 amplitudes between PNW and NPNW stimuli was smallest for LVF (RH) presentations with RH recordings. Again, the RH does not seem able to processes PNWs phonetically.

ERP findings from Experiment 3 were somewhat disappointing, since there were no laterality effects found, and the N400 was absent. However, it appears that interhemispheric cooperation may be indicated in Experiment 3 since presentation of bilateral identical stimuli resulted in larger LPC amplitudes than did bilateral non-identical stimuli. There was also only one weak priming effect found exclusively for temporal sites where LURA (LH primed), but not LARU and DU, elicited increased LPC amplitudes to the level of the redundant conditions. It is difficult to draw any firm conclusions about these data because the task may have resulted in automatic processing for redundancy instead of controlled processing for associative priming, or perhaps a combination of strategies was used. In addition, 14 females and only 4 males (all right-handed) participated in Experiment 3. This may have also contributed to the lack of laterality effects since previous research indicates females are less lateralized, in

part because they have a larger isthmus (posterior corpus callosum section) which is thought to be involved in language processing (Clarke, et al., 1994).

Conclusions and Future Directions

The major findings from this study include both behavioral and ERP results. Visual field effects were present in all studies, which provides further evidence that the LH is dominant for language processing. Lateralization of targets may have affected the pattern of ERP results found for lexical decision, where NPNWs unexpectedly elicited an N400. Additional ERP research using lateralized targets and tasks with higher cognitive demands would guide interpretations of this effect, particularly since the N400 is more sensitive to deeper processing. Bilateral presentation of stimuli helped to unveil the effects of RH priming in Experiment 3. Although RH performance reflected in the behavioral findings did not appear to benefit from LVF (RH) priming, it did reduce the RVF (LH) advantage, implying relative hemispheric specialization (direct access model) while arguing against absolute hemispheric specialization (callosal relay model) since both hemispheres appear capable of performing the task independently.

Although ERP findings in Experiments 1 and 2 did not parallel the behavioral findings, they do support behavioral evidence from previous research showing hemispheric differences for processing non-words. The difference in N400 amplitudes that was found for pronounceability over the LH but not over the

RH for provide strong neurophysiological support of the LH's ability and the RH's lack of ability to process non-words in a phoneme-to-grapheme manner.

Lastly, component overlap was reduced by manipulating task demands, but at the cost of changing the pattern of later ERPs across the various word and non-word conditions, implicating the use of different cognitive strategies in Experiment 2. Therefore, it is recommended that other methods or careful consideration of task manipulations be used to control for component overlap.

All of the experiments provided useful information for determining whether the callosal-relay, direct-access, or combination model most accurately explains certain aspects of language processing. Throughout this study, priming effects were found for both hemispheres with behavioral and ERP measures. During later stages of cognitive processing, ERP components emerged over both hemispheres, with VF or hemispheric differences, depending on the task and component measured. These findings argue against the callosal-relay model for language processing in these tasks, since both hemispheres are capable of performing the tasks, rather than only the LH. However, the direct-access model is not strictly indicated for language processing during these tasks either, since ERP components were recorded not only for direct VF-hemisphere presentations, but also for indirect VF-hemisphere presentations of stimuli, indicating some callosal transfer of information. Therefore, a combination model appears to be the most appropriate explanation for the findings in this study since ERP activity was generally present over both hemispheres, and ERP amplitudes

for the later cognitive components were affected differently by task demands in addition to VF-hemisphere presentations.

Limitations of this study include no inclusion of a gender variable, particularly since females are thought to have more interhemispheric sharing which would reduce laterality effects. Analyses of ERPs during T2 in Experiments 1 and 2 would also provide findings that could be correlated more closely with behavioral data that reflect processing of T2. Future research should consider changes in the design of Experiment 3 to address the lack of significant ERP findings. Perhaps use of a task with higher cognitive demands, such as lexical decision with bilateral targets or even centrally presenting a sentence word by word with two endings shown bilaterally in the VFs (no decision) would be more likely to show N400 effects. Although this study has provided answers to some of the questions regarding hemispheric differences in language processing, many more remain unanswered and should be further investigated with both behavioral and ERP measures.

APPENDIX

TABLE

Table 1

Word association norms

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
APE	monkey	.41	gorilla	.15	man	.05
ARM	leg	.41	hand	.13	chair	.05
BANNER	flag	.28	sign	.13	parade	.04
BEARD	man	.14	hair(y)	.17	mustache	.09
BLOUSE	shirt	.32	skirt	.09	silk	.07
BOY	girl	.70	man	.03	toy	.01
BRAIN	smart	.16	head	.12	dead	.07
CABIN	log(s)	.28	wood(s)	.21	fever	.12
CAFE	coffee	.39	food	.15	eat	.04

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
CAMERA	picture(s)	.38	film	.17	lens	.10
CANNON	ball	.29	war	.11	camera	.06
CAT	dog	.47	mouse	.08	meow	.03
CEREAL	milk	.25	breakfast	.15	bowl	.06
CHAPEL	church	.58	wedding	.10	marriage	.09
CIRCUS	clown(s)	.45	elephant(s)	.11	tent	.04
CLOUD	sky	.33	rain	.20	nine	.10
COAST	beach	.20	soap	.10	water	.10
COKE	drink	.22	Pepsi	.09	soda	.08
CORN	cob	.30	yellow	.09	husk	.06
COW	milk	.30	moo	.16	horse	.04

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
CRADLE	baby	.71	rock	.12	grave	.02
CRAYON	color(s)	.38	red	.10	crayola	.05
CRUMB	bread	.30	cake	.19	cookie	.09
DAGGER	knife	.44	sword	.09	sharp	.05
DANCER	ballet	.20	music	.05	ballerina	.04
DAY	night	.59	light	.05	long	.04
DOCTOR	nurse	.23	sick	.08	medicine	.04
DUNE	sand	.51	buggy	.10	movie	.06
DUSK	dawn	.49	dark	.12	night	.09
ELM	tree	.66	street	.21	oak	.01
FAWN	deer	.52	Bambi	.05	doe	.04

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
FILM	movie	.26	camera	.25	picture(s)	.10
FLAME	fire	.45	hot	.12	burn	.07
GEM	stone	.31	diamond	.17	ruby	.09
GIFT	present	.31	birthday	.08	Christmas	.06
GIN	tonic	.23	juice	.11	drink	.09
GLOBE	world	.49	earth	.12	round	.06
GLOVE	hand	.46	cold	.05	baseball	.04
GOLD	silver	.33	ring	.13	money	.05
GOWN	dress	.13	night	.10	wedding	.09
HAM	pig	.15	sandwich	.10	eggs	.08
HAMMER	nail(s)	.67	tool	.05	M.C.	.02

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
HERB	spice	.16	garden	.10	weed	.06
HONEY	bee(s)	.33	sweet	.21	bear	.07
HOTEL	room	.19	motel	.16	sleep	.10
IVORY	soap	.30	white	.17	elephant	.12
KING	queen	.55	crown	.06	kong	.03
LAKE	water	.25	boat	.08	fish	.06
LAWN	mow(er)	.34	grass	.27	green	.13
LEAF	tree	.49	green	.15	fall	.04
LIMB	tree	.40	arm	.25	leg	.09
LIME	lemon	.41	green	.10	sour	.08
LIPS	kiss	.40	red	.10	mouth	.07

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
LOCK	key	.44	door	.18	smith	.04
LUNCH	food	.17	dinner	.14	sandwich	.10
MAN	woman(en)	.64	boy	.05	big	.02
MEAL	food	.27	eat	.12	dinner	.11
MINK	coat	.58	fur	.11	animal	.07
MOUSE	cat	.21	rat	.13	trap	.11
MUG	coffee	.39	beer	.13	cup	.12
NEST	bird(s)	.66	egg(s)	.19	home	.01
NICKEL	dime	.47	money	.20	silver	.04
ORCHID	flower(s)	.54	purple	.09	wild	.05
PAGE	book	.27	paper	.16	number	.10

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
PALACE	king	.18	castle	.15	queen	.06
PENCIL	pen	.36	lead	.10	write	.09
PEPPER	salt	.58	hot	.11	sneeze	.04
PIE	apple	.29	cherry	.11	cake	.09
PILOT	(air)plane	.61	fly	.06	crash	.02
PONY	horse	.43	tail	.16	ride	.11
ROBIN	bird	.48	hood	.13	red	.07
ROCKET	ship	.20	space	.12	scientist	.08
RUG	carpet	.25	floor	.19	soft	.03
RUM	coke	.23	drink	.12	alcohol	.09
SANDAL	shoe(s)	.28	foot(feet)	.28	summer	.05

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
SAUCER	cup	.37	flying	.15	plate	.08
SCOTCH	tape	.34	drink	.09	guard	.07
SILVER	gold	.39	ware	.05	jewelry	.04
SKIS	snow	.41	water	.12	slope(s)	.07
SLOPE	ski(ing)	.37	hill	.15	mountain	.07
SMILE	happy	.35	teeth	.14	frown	.12
SOCKS	shoe(s)	.47	foot(feet)	.11	white	.10
SODA	pop	.29	coke	.26	drink	.10
SOIL	dirt(y)	.54	plant	.05	earth	.04
SPIDER	web	.44	black	.06	man	.05
STAR	sky	.19	night	.13	bright	.10

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
STONE	rock(s)	.39	hard	.07	throw	.05
SUIT	tie	.25	man	.07	business	.05
SUNSET	sunrise	.15	beautiful	.07	pretty	.06
SUNTAN	lotion	.15	dark	.12	oil	.10
SUPPER	dinner	.39	food	.11	eat	.07
TABLE	chair(s)	.37	cloth	.12	tennis	.04
TENT	camp(ing)	.57	green	.02	woods	.02
TOAD	frog	.58	wart(s)	.08	stool	.05
TOE	foot(feet)	.39	nail	.15	jam	.07
TROUT	fish(ing)	.81	rainbow	.01	stream	.01
TRUCK	car	.24	driver	.11	stop	.09

(Table continues)

Stimulus word	Most frequent response		2nd Most frequent response		3rd Most frequent response	
UNCLE	aunt	.43	Tom	.06	Sam	.06
WIG	hair	.43	fake	.11	bald	.05
ZOO	animal(s)	.54	monkey(s)	.08	zebra	.06

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