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Hemispheric Differences in The Effect of Selective Attention on The Electrophysiological Response to Semantic Processing

by

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Abstract

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Adviser: Dr. Diana Deacon

Two event-related potentials experiments examined the extent to which color-cued selective attention differentially modified semantic processing of single words in the cerebral hemispheres. Attentional status of the prime and target were manipulated within and between experiments. Lateralized presentation of associatively and categorically related words that shared common features (DOCTOR-NURSE) produced a significant N400 semantic priming effect in the left visual field/right hemisphere regardless of the attentional status of the prime or target. For the right visual field/left hemisphere, significant priming was produced in all conditions except when both the prime and target were ignored. In conjunction with ERP findings of effective early selection based on color, these results are interpreted as providing evidence for a view of attention as acting at multiple stages in the reading process, and against a simple sensory gain control interpretation of selective attention.

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This thesis is dedicated to my son Sean and above all my wife Shannon, who has always stood by me, and who has always demanded the best from me in work and in life.

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Table of Contents

List of Tables

List of Figures

I. Introduction

Overview

This paper presents evidence that bears on two distinct, but interrelated fields: the study of when and how attention modifies mental processes, and how the meaning of words are represented in the brain. The first part of this work will provide a brief review of the common theories of meaning representation and processing, highlight some relevant studies of attention, and review studies that have used neuroscience methods to study the interaction between attentional and meaning processing systems. The second part of the paper presents original research that utilizes a color-cued selective attentional paradigm to explore hemispheric specializations in the attentional control of the processing of single words. The method of event-related potentials (ERPs) was used to investigate this phenomenon because of its ability to make fine-grained temporal distinctions between otherwise unobservable cognitive processes. The final portion of the literature review will focus on summarizing studies that have investigated attention and semantics using ERP methods. The specific goals and hypotheses of the current research will be outlined, before presenting the empirical portion of the paper.

Review of the Literature

Whether attention acts early or late to influence the perceptual and cognitive processing of words remains a vital topic of research within psychology. This dichotomy, often framed in terms of the early "bottleneck" or "attenuation" theories

(Broadbent, 1958; Triesman, 1969) versus the "late selection" theories (Norman, 1969; Deutsch & Deutsch, 1963; Marcel, 1983a; 1983b), has served a useful role in framing the issues for exploration and fueling an active debate. In 1992, Laberge stated that "Today, most researchers agree that late selection can take place on the basis of the individuals momentary goals and response tendencies. What is still controversial is whether or not early selection occurs at all (p. 24)." While solid electrophysiological evidence has been accumulating since the 1970's, research from the last decade has firmly established the plausibility of early selection; namely, evidence has accumulated that attention can both enhance and suppress the neural activity associated with attended and unattended stimuli, respectively (Luck et al., 1994; Luck and Hillyard, 1995; Mangun and Hillyard, 1991). Furthermore this modulation can act as early as 80 msec post stimulus (Mangun et al., 1993). The early selection position states that the processing of stimuli within the focus of spatial attention are enhanced as soon as they are identified as being: 1) within the expected region of space, or 2) possessing the proper stimulus feature, such as the correct color, shape, or size (Näätanen, 1992). Stimuli that do not possess one of the attributes just described are deemed irrelevant by the system, and either blocked from further processing (Broadbent, 1958), or attenuated (Moray, 1959; Treisman, 1960). Additionally, neuroimaging and electrophysiological studies have emerged that failed to support the notion of late selection at all (Rees, Russel, Frith, & Driver, 1999; McCarthy and Nobre, 1993).

On the other hand, researchers have found both behavioral (Besner & Jolicoeur, 1994), and electrophysiological evidence (Otten, Rugg, & Doyle, 1993) of late-acting and more persistent mechanisms that are consistent with late selection, and that consciously unavailable stimuli can even act to influence response preparation and execution (Eimer & Schlaghecken, 1998; Eimer, 1999). Besner and Jolicoeur (1994) matched early versus late selection accounts against one another in a visual pre-cuing paradigm. Across multiple experiments, they found that stimulus quality effects were attenuated with a preview of the letter array; a result that favored a late-selection explanation. Eimer (1999) demonstrated that the lateralized readiness potential, a brain potential associated with response preparation, to a target stimulus was reliably modulated by a prior stimulus that was masked so as to be below threshold, and thus unavailable for attentional processing.

Support for late selection has most often been provided in the form of evidence of semantic processing occurring in conjunction with evidence of the effective direction of attention away from the stimulus of interest. These criteria were met in a study by Otten, Rugg, & Doyle (1993), as indicated by the presence of early attention-dependent electrophysiological components as well as a significant, late, negative component associated with stimulus repetition. Similarly, behavioral techniques have used increasingly refined methods that provide stringent tests for the question of whether stimuli that are not consciously available, are nonetheless processed up to and including the level of meaning (Greenwald, Klinger, & Liu, 1989; Greenwald, Klinger, & Schuh, 1995; Greenwald, Draine, & Abrahms, 1996). In these studies, the relative contributions of conscious and unconscious processing were accounted for by applying a regression based errors-in method of data analysis to the data, which have consistently led the authors to the same conclusion: unconscious semantic processing occurs even under the most stringent of methodological controls. Thus, the debate begun over 40 years ago appears far from settled.

A primary advantage for early selection processes is that stimuli that are task-irrelevant are prevented from draining limited attentional resources away from the processing of other, relevant stimuli (Broadbent, 1958). However, an equally useful role has been hypothesized for late selection mechanisms of attention, which is that a system that continues to process irrelevant stimuli "in the background" can quickly switch to those stimuli if and when they are found to possess some information that could be important to the individual, as in the case of the classic "cocktail party effect," (Cherry, 1953). No empirical test to date has been able to establish that one view of attention is superior to another at accounting for the wide array of attention-related phenomenon in the literature (See Pashler, 1998, Chapter 1, for a review).

Recently, researchers have begun to find evidence that attention can act both early on and later in the modulation of cognitive processes. Therefore, the job for new research is to specify the conditions under which attention will act, the time course of such action, and the neural substrates that underlie attention (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990; Parasuraman, 1998; Gazzanaga, 2000; Hillyard, Vogel, & Luck, 1999). The difficulty of this approach is in finding a unifying theory that can tie in such diverse pieces of evidence. One possibility is that early and late selection are both at work whenever a reader is attempting to extract meaning from written stimuli, but that the inhibitory aspects of late selection sometimes mask ongoing, higher level processing. Specifically, if one cerebral hemisphere maintained a trace of all incoming words without regard to their goal or task relevance, while the other hemisphere was able to select for and suppress irrelevant stimuli, then the net result would be a highly adaptive system that could process language quickly while still maintaining the capacity for error correction. This proposal is not new. Numerous authors have posited different roles for the right and left hemispheres in the controlled processing of language (Burgess & Simpson, 1988; Faust & Gernsbaucher, 1996; Beeman, 1997; Chiarello, Senehi, & Nuding, 1987). What is new is the idea that not only is semantic information represented in qualitatively, not quantitatively different formats in the hemispheres, but also that this contributes to the susceptibility of one hemisphere to attentional control while another is largely impervious to the effects of attention.

Such a claim of representational differences between the cerebral hemispheres has recently been advanced by Deacon, Grose-Fifer, Yang, Stanick, Hewitt, & Dynowska, (2003). They have accumulated evidence from behavioral and electrophysiological studies that suggests that the left hemisphere may be organized as an automatic spreading activation based local network, while the right hemisphere is organized as a distributed system of processing nodes. In order to understand their proposal it is necessary to review common theories of semantic representation, and to highlight the evidence for and against these different views of semantic memory.

Models of Semantic Memory

Semantic memory has been conceptualized as a system for representing general world knowledge, linguistic skill, and aspects of vocabulary (Tulving, 1972, 1983). This can be contrasted with autobiographical memory for contextually specific events, which has been labeled episodic memory (Heilman & Valenstein, 1993). The dominant models of semantic memory that have appeared over the last four decades can be roughly divided into one of two types: local or distributed. At the most elementary level, local models are those in which each "concept" in semantic memory has a unique location, or "node" in memory, whereas distributed systems posit that the same representational structures subserve multiple "concepts". Concepts, as defined in Collins & Loftus' (1975) local theory and used in both local and distributed models, are "particular senses of words or phrases." For example, "car," "driving a car," and "the particular car that I own" could all be thought of as concepts. How these concepts are represented, and how they interact is still far from understood.

A growing body of neuroimaging evidence exists for the localization of semantic processing to particular regions of the brain, including the left superior and medial temporal gyrus (Price, Moore, Humphreys, & Wise, 1997; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996; Wise et al., 1991), and the left inferior frontal regions (Thompson-Schill, 1991; Roskies et al., 2001; Gabrieli, Desmond, Demb, Vaidya, & Glover, 1998; Binder et al., 1997; Wagner, Desmond, Demb, Glover, &Gabrieli, 1997; Gabrieli et al., 1996; Demb et al., 1995). This does not mean, however, that the semantic information, per se, is "located" in these regions, but only that these regions subserve the access and processing of information that is likely distributed throughout a distributed cortical network (Cabeza & Nyberg, 2000). Local models thus far have not been structural descriptions, but instead functional conceptualizations of the semantic system.

Local Models

The appeal of local models has been in their conceptual and diagrammatic simplicity. As seen in Figure 1, concepts are represented as circles, which depict a unique informational location, or node. These nodes are then connected through links that determine the strength, as well as the type, of the relationship between the nodes. The Collins and Quillian (1969) formulation of a semantic network allowed for 5 basic types of relationships, as well as for viewing links as a type of node, or concept, in themselves. Again, the advantage is flexibility, but the disadvantage is that it is difficult to conceive of experiments that could disconfirm such a flexible theory in a way that would require it to be discarded. Perhaps the best candidates for such experiments to date have been those involving the interposition of an unrelated intervening item between the first and second stimuli in a semantic priming paradigm. These studies, which have yielded highly mixed results, will be discussed in detail below.

In addition to the Collins and Loftus (1975), and the Posner & Snyder (1975) model that introduced the element of controlled processing into semantic network theory, the models of John Anderson (1974, 1976, 1983, 1999) were based on the assumption of spreading activation through a local network. Anderson's main finding was that a "fan effect" occurred in which the ease of recognition of a target item was inversely related to the number of concepts that it was associated to during a study phase. This effect, expressed most completely in the Adaptive Control of Thought (ACT) (Anderson, 1983), and ACT-R (revised) (Anderson, 1993) theories, provided support for the notion that when a word stimulus is presented, its corresponding representation becomes activated. This activation is finite, similar to an electrical charge, and it then spreads out to all related concepts automatically. According to ACT, because the activation is of finite level and duration, the larger the number of related concepts, the smaller amount of activation any one related concept would receive.

This is best illustrated in the simple propositional statements often used by Anderson, such as "A hippie is in the park." When hippie is paired with park, house, and bank (3 pairs) during study, it takes longer to retrieve at test than if it were studies with park alone (1 pair).

The results of multiple experiments have lead, generally, to a confirmation of the feasibility of spreading activation as a mechanism for explaining relationships between items in associative memory (Anderson & Reder, 1999). In a recent series of articles, M.C. Anderson and his associates have proposed that the fan effect can be equally well explained in terms of inhibitory processes (see Anderson and Spelman, 1995, for a summary), as opposed to a simple dilution of facilitation across multiple items. In a paradigm similar to the typical study-and-test method of Anderson, these authors had participants practice particular associations to a category heading, e.g., study "blood" and "tomato" for the category "red." One of the associates received more practice (here, blood), and subjects demonstrated an (unsurprising) boost in recall for that item. Interestingly, the less studied item (here, tomato) not only yielded poorer recall performance, but novel members of the same category as the less studied item also showed a recall decrement at test. For instance, the red food “strawberry” was more difficult to recall than another food (crackers) that did not fit into the category of red. While ACT-R did not predict such an effect, the presence of inhibition is in no way incompatible with spreading activation, assuming that the locus of the inhibition can be shown to operate in a manner that modulates, but does not replace automatic spreading activation. Anderson & Reder (1999) argue that their model can accomplish this theoretical feat with a minimum of adjustment.

The last thirty years have produced relatively little change in the basic conceptualization of the local semantic network as a series of nodes over which activation spreads. However, the field has been rife with alternative explanations for the priming effect, which has been the primary tool for the study of semantic networks.

Word Identification and Models of Semantic Priming

Semantic priming is the processing advantage that occurs when a word (the target) is preceded by another word (the prime) that is related in meaning to the target. The nature of the meaning relationship can be one or more of the following, but is not limited to: shared functional, or visual features, membership in the same semantic category, or a simple associative relationship, such as ice-cream - scoop. An example of a typical semantic priming sequence is presented below in Figure 2.

The phenomenon of priming has become ubiquitous in cognitive psychology, and the existence of positive semantic priming has been solidly established (Neely, 1991).

The nature of the operations behind semantic priming, on the other hand, are far from completely understood. The operations that take place during semantic priming depend on the nature of semantic representation, as well as the operations that occur during the specific task required of the subject. The strength and direction of priming effects vary greatly with the subject's task, the stimulus, and the display parameters involved in task presentation. With that in mind, we can review some of the most influential theories of priming, and discuss the most common parameters that have been found to influence priming in meaningful ways.

As mentioned above, perhaps the best known theory of semantic priming is that of Collins & Loftus (1975). Their explanation of semantic priming rested on 1) their proposal that semantic information is best described as being organized as a local network (see above), and 2) their notion of the way the search of this network takes place. When a word is presented to a subject, for instance the prime "DOCTOR," then the activation generated by the lexical identification of the stimulus begins to radiate out to all related concepts through the series of associative links described above. These authors proposed that, in addition to the nodes and links just described, a system of "tags" is included that marks the path that spreading activation follows. As spreading activation travels, it leaves behind a trace (tag) that indicates not only its node of origin, but the last node that it had passed through.

When the target is presented, the subject initiates a search of their semantic memory in order to find the lexical entry of the word, in the case of a lexical decision task, or in order to find the word's semantic properties, such as its associates, in the case of a semantic relatedness judgement task. This theory was designed to account for data in semantic verification tasks, of the sort, "All apples are fruit." In order to check for the truth of this proposition, the subject is thought to initiate a memory search to compare the information about these two items. If the word Macintosh had been presented prior to the to-be-verified proposition, then all of its associatively related concepts, including "apple", will recently have had activation tags placed along their network. The result of this is that when the spreading activation from related tags "intersects," that is, tags from the two concepts are found in the same place, then an evaluation process occurs that traces each path back to its start. If the concepts link up, then they are judged to be related. If they do not link up, they are unrelated.

With this in mind, it is important to note that the process thought to be in operation during these tasks is word identification. A great deal of effort has been spent to try to isolate the nature of the processes underlying word identification, and the evidence tends now to point to the notion that it can, but does not normally, proceed without attention (Besner & Stolz, 1998). The first authors to popularize the distinction between automatic and controlled processes in word identification were Posner and Snyder (1975), who described studies that revealed that priming was greatly influenced by the length of delay between prime and target. At short stimulus onset asynchronies (SOA) of less than 250 msec, only facilitatory effects were found, while at long SOAs, greater than about 750 msec, both facilitation and inhibition were possible. It was theorized that in addition to the automatic spreading activation already described, when subjects were given ample time, they would use controlled processes as well.

The two most often discussed types of controlled processes are expectancy generation and various forms of post-lexical matching (De Groot, 1983 , De Groot et al., 1982). The later matching processes are referred to as post-lexical because they are thought to occur after the word form and meaning of a word stimulus have been accessed, and the priming advantage is theorized to occur somewhere between meaning access and the motor response. This dichotomy is somewhat misleading, in that even in the original Collins and Quillian (1969) formulation of spreading activation in a local network, the priming effect produced by the system of activation tags was not realized until after activation had spread through the network and the paths were evaluated in a memory search process.

Another mechanism thought to be active at long SOAs is semantic expectancy. When subjects are exposed to an experimental situation in which the prime is predictive of the target, they begin to actively generate a set of possible targets after the appearance of the prime. This process is illustrated in Figure 3. Generally, when the proportion of primes and targets is relatively high (≥ .50), it would be reasonable to adopt such a strategy. If a subject generates the target as part of his or her expectancy set, then the response to that target should be facilitated due to its prior activation by the expectancy mechanism. Although this strategy occurs after the prime has been processed, it does occur before the meaning of the target word has been processed, and so in that sense is a controlled pre-lexical process. In other words, it is distinct from post-lexical matching because its effect is to change the level of activation of the target before it is actually encountered, not to facilitate a matching processes after lexical activation. All of the mechanisms discussed in this section have been proposed to account for experimental data in local conceptions of a semantic network, but other possibilities for lexical-semantic organization exist.

Feature-based Semantic Models

Although the models thus far have assumed that concepts are relatively unitary constructions that are linked together through associative connections, other models have been proposed that view concepts as aggregates of features. In one of the best known theories, that of Smith, Shoben, & Rips (1974), concepts are composed of both defining and characteristic features. The former are thought to be those elements of a concept that are necessary and sufficient for the basic definition of the concept, and the latter are often associated with, but not critical to, a concept's meaning. More modern featural theory researchers have divided the majority of features into structural and functional features. Structural features are composed of both sensory aspects (square-shaped), and material qualities (made of clay) (Moss, Tyler, & Jennings, 1997). Functional features permit the comparison of "spoon" and "shovel", because both can be used to scoop. Like the Collins and Loftus model, this model was designed to account for performance on a sentence verification task in which subjects were asked to evaluate the truth of a statement such as "All robins are birds." Memory access is accomplished through a two-stage search process in which 1) "a set of category names are retrieved which contain the names of all categories that have some members in common with the category of the predicate noun (bird in the previous example)," and 2) "a feature by feature comparison process occurs in which the attributes of the subject and predicate of the sentence are checked for a match" (Smith, Shoben, & Rips, 1974).

One major advantage of such a model is that it permits a detailed mapping of semantic space, such that the distances between concepts can be determined along empirically derived continua. Smith et al. accomplished this by the use of typicality ratings as the dependent measure used in a factor analysis technique. Such a semantic space allows for predictions to be made about the typicality of any new instance of a concept that is introduced into such a space. Network models must suppose the existence of a new node, not only for new concepts, but for even slightly difference senses of an existing concept. For instance, the notion of a "soda" and that of a "large soda" would have separate representations in a local network, while a feature model would need only to change the weight on the dimension of size to encode this second concept. This would seem to be a more precise and economical format for information storage.

Another advantage of such a conception of semantic representation is its ability to specify what elements are included in the definition of any concept. For instance, the precise sense of the term "dog", as situated in a local network, may not be exactly the same for all researchers. In practice, however, this is difficult owing to several factors. First, it may be impossible to determine what constitutes a necessary feature for any category. For example, the concept of "furniture" may typically include tables and chairs, which share four legs and the ability to hold other items on top of them. On the other hand, "furniture" may also contain bean-bag chairs, with no legs, and grandfather clocks, which do not hold other objects. Second, there may be a great deal of difference between the featural composition of a concept between individuals. While two people may be able to agree that the furry creature standing before them should be labeled "dog", this does not mean that they have the same set of key attributes in their representations of "dog."

The model of Smith et al. (1974) was criticized so effectively by Collins and Loftus (1975) that it lost a good deal of influence in the field of semantic research. Besides its difficulty in distinguishing defining from characteristic features, the Smith et al. model proposed that people do not search the superordinate category when making category judgments. Often times, as stated in Collins and Loftus, people must decide category membership not based on defining features, but simply on whether they had learned explicitly that "X was a Y." The example given by Collins and Loftus was of a person being uncertain of the properties of a sponge, but still being able to correctly categorize it as an animal due to their explicit learning of that fact. One way to view the critical difference between these types of theories is that featural theories permit a calculation of the semantic status of each concept online, based on the evidence of its featural composition. Local network theories propose that the outputs of processes are stored and linked together. In other words, whereas features may be used to construct and judge instances of categories, local nodes are the output of such constructive, or rote learning, processes.

Distributed Models

The model of Masson (1995) (also, Masson & Borowski, 1998) is "distributed" in that it postulates that every concept is represented over a large array of processing units that are generally the same within any one module of the system. Such an array consists of multiple layers, or levels, starting with an input unit, followed by some number of hidden layers, and finally an output layer. This arrangement is illustrated in Figure 4.

Masson's model proposes the division of the neural network into three main sub-networks based on their representational content: orthographic units, phonological units, and meaning units. These subsystems are completely interconnected though feed-forward and feed-back pathways, thus allowing the output of semantic and phonological analyses to influence the activity state of the orthographic units. This feature allows the network to account for such basic phenomena as the word-superiority effect (Reicher, 1969), in which word identification is faster than identification of an equivalent non-word string. Here, lexical level information biases orthographic processing units, causing a more rapid identification of previously encountered (legal) word forms.

If a word is presented visually, the orthographic system takes the word form as its input, the input is transduced into values that are passed to an unspecified number of intermediate units, and these values are passed as output to a higher-level subsystem. Orthographic output passes either directly to the semantic unit, or by way of the phonological unit to the semantic unit. This architecture is necessary to account for evidence suggesting that while phonological activation may be the default result of an orthographic analysis, meaning activation can take place in the absence of concomitant phonological analysis (Jared & Seidenberg, 1991). Whenever input enters one of the distributed processing subsystems, it is cycled through repeatedly, with output being fed back into the input channel until the most stable pattern of activation is found. In this sense, "identification" at any processing level means the point at which error between input and output is minimized.

When a prime appears in this type of distributed model, it causes the processing units to take on the values associated with that word at each level of analysis. Because the processing units can only hold one value at a time, if a related target appears it will find the current pattern of semantic activation to be similar to its own. Thus the time necessary for the target to reach a stable level of representation will be shortened. Unrelated words require a resetting of the units, while neutral stimuli, for example, a row of x's, leave the network in a relatively unbiased state. Therefore, RT for tasks requiring word identification should be slowest for unrelated, moderate for neutral, and quickest for related pairs of words. In this way, this type of distributed model can account for the same findings of inhibition for unrelated words at long SOAs that were discussed earlier in the work of Posner and Snyder (1975).

As discussed in Masson (1995), the primary test of the utility of such models is in their ability to account for existing data parsimoniously, and to make unique and accurate predictions. The primary experimental evidence for the distributed model discussed by Masson concerns its ability to accurately predict the magnitude and direction of semantic priming effects in a situation in which an unrelated item is interposed between a related prime and target.

The original formulation of local network models predicts that an intervening item should have no effect on the strength of priming effects because activation spreads automatically to all nodes in the network. Presenting an intervening item should add another source of activation to the network, but not disrupt the initial activation. Because distributed networks can represent only one concept at a time in their processing units, the intervening item should disrupt priming to the extent that it is different from the activation pattern of the prime and target. Thus unrelated intervening items should disrupt priming the most, and neutral stimuli (like "XXXX") should have a marginally disruptive influence.

Masson reports two studies designed to test these predictions. Study 1 presented subjects with a prime, intervening item on some trials, and target, for 200 msec each, with an SOA of 400 msec. The subject's task was to name the target as quickly as possible. As predicted by his model, Masson found that the unrelated intervening item significantly disrupted priming when compared to the condition where the target followed the prime directly. In a second experiment in which priming across trials was assessed, Masson lengthened both the duration and SOA of the stimuli and arranged the items so that the target of one pair would serve as a prime to the next pair. He predicted that under these conditions the disruption of priming seen in experiment 1 would diminish because the degree of disruption would be proportional to the amount of processing devoted to the intervening item relative to the prime. The pattern of activation set up when processing the intervening item is more likely to disrupt priming if 1) the prime's pattern is less established, and 2) the intervening item's pattern is allowed to completely stabilize in the system. While the complexity of his results render them prohibitively large to report in detail, he found that the intervening item produced disruption as predicted.

In his paper, Masson (1995) attempted to provide support for the plausibility of an alternative representational scheme to the local network. He was initially successful. On the other hand, he pointed out that the model was incomplete in that it did not provide mechanisms to account for many of the common strategic processing factors encountered in priming research, including proportion of related to unrelated prime-target pairs (so-called relatedness proportion, or RP), proportion of non-words, and semantic expectancy strategies. It also lacked the ability to account for a "learning effect" apparent in a comparison of the two studies. Briefly, when a neutral word that is the same on all trials is used as the intervening item ("Ready"), subjects slowly become habituated to it, and the pattern of disruption changes. The failure of any of these models to account for how the semantic system can be restructured to permit new word learning is a serious shortcoming, as word learning is one of the hallmarks of human linguistic behavior.

Summary and New Model Prosed by Deacon et al.

Evidence, sometimes contradictory, exists for both local and distributed conceptualizations of the semantic system. Both automatic and controlled processes appear necessary to account for the majority of semantic priming results (Neely, 1991; De Groot & Nas, 1991). The semantic system may be indexed according to simple association, semantic feature composition, and category membership. Instead of arguing for the supremacy of one or another aspect of the above theories, it may be wise to try to adopt the best ideas contained within each in order to come to an adequately rich understanding of semantic memory. However, it is difficult to find a unifying theory that can tie in such diverse pieces of evidence.

One possibility, as introduced above, is that both local and distributed aspects of the semantic system exist in the cortex, but that they are more or less localized to each cerebral hemisphere (Deacon et al., under review). Based on several studies in their laboratory, Deacon et al. have argued that the left hemisphere (LH) is organized according to a local network, such as that of Collins (1969, reviewed above), while the right hemisphere (RH) is organized as a distributed network, such as that of Masson (1995).

In brief, the evidence for this model comes from electrophysiological studies of semantic priming that have utilized visual half-field presentation. The primary dependent measure used in these studies, the N400, is an endogenous, negative component that peaks between 300 and 500 msec post-stimulus, with an amplitude that is sensitive to semantic priming manipulations. The N400 was first discovered in a sentence-based paradigm, in which the critical stimulus was the terminal word in a sentence that was either semantically congruous or incongruous (Kutas & Hillyard, 1980; Kutas & Hillyard, 1984). The initial functional interpretation of the N400 was that it was a general response to word processing Kutas & Hillyard, 1980). The N400 was later interpreted as indexing the probability of occurrence of the terminal word, based on the prior sentence context. Since then, Brown and Hagoort (1993) states that the N400 was an index of a post-lexical checking processes. This was said to occur after the lexical entry for the target had been activated, and after conscious resources had been allocated to that lexical information. Since that time many studies have rendered that interpretation untenable (see Deacon & Shelley-Tremblay, 2000 for a review).

The best evidence that the N400 is not an index of post-lexical integration is that the N400 priming effect is seen when the prime is masked to below threshold for conscious recognition (Deacon, Hewitt, Yang, & Nagata, 2000; Schneyer, Allen, & Forster, 1994). Additionally, it is elicitated in single word priming paradigms (Bentin & Kutas, 1988), where the subject would have no a priori reason to attempt to integrate the target with the prime. Some have argued that single word priming studies can still be taken as evidence for a post-lexical interpretation because the reader adopts the default strategy developed in normal reading of text, and thus treats the word pair as if it were part of a larger context (Holcomb, 1993).

However, the N400 occurs under conditions where the use of conscious, post-lexical processes are highly unlikely. First, it occurs when the prime-target SOA is too short for post-lexical processes to be engaged (Boddy, 1986; Anderson & Holcomb, 1995). Deacon, Shelley-Tremblay, Yang, and Ritter (in preparation) have also shown that the N400 is, contrary to Holcomb (1993), sensitive to stimulus degradation. This indicates that the N400 is operating at or before the level of lexical access, where stimulus degradation has been previously shown to affect processing (Meyer, Schvaneveldt, & Rudy, 1975). With this evidence in mind, it is reasonable to postulate that modulations in the amplitude of N400 tell us something about the amount of processing necessary at the level of lexical activation. This is not to say that the N400 cannot index the effect of controlled processes on lexical activation, assuming that such processes are supposed to affect the level of lexical activation of a target before its meaning is accessed. That is, the mechanisms of expectancy generation (guessing the target, see discussion of de Groot, above) and other attentionally based mechanisms should modulate the N400 by changing the resting level of activation of the target.

In the first experiment of Deacon et al. (under review), subjects were presented with concrete nouns as prime and target words. The primes were either semantically unrelated (baseline), related according to the structure or function of the target. For example, the target "WIG" could be preceded by "MOP," which shares the same global shape. The significance of this stimulus set is that Deacon et al. hypothesized that only the right hemisphere would benefit from such primes, because they are not associates, but share semantic features. This would be the case for a distributed feature network in which common association is not encoded, per se, but in which priming is the result of shared features (and therefore pre-activated nodes) between the prime and target representation. For example, "MOP" is presented to the subject. Once processed by the network, if *mop* (the concept) has the features "has strands," "hangs down," and "rounded contour," then when the network is presented with "WIG," the overlap between features results in less processing time, and measurably different N400 , than if "WIG" is preceded by "TRUCK." Deacon et al. postulated that the LH would not benefit from such featural overlap because it represents word meaning in the form of a local network that relies on associative links only. The ERP data obtained were in support of this dichotomy, in that significant N400 priming was found only for words presented to the LVF/RH.

In the second experiment, subjects received stimuli that were not from the same semantic category, and thus shared few semantic/perceptual features, but nonetheless were highly associated (e.g. "DOCTOR," "SCALPEL"). In this study, the pattern of results was reversed, such that only the RVF/LH evidenced significant N400 priming. In a related study from the same laboratory, subjects viewed primes that were followed by either a target or an unrelated intervening item (Deacon, Grose-Fifer, Nagata, & Dynowska, in preparation). Recall that when an intervening item is interposed between a prime and target, automatic spreading activation should not be disrupted in a local network because the facilitation spreads quickly to all associated nodes via pre-established, relatively stable links. A distributed network, on the other hand, should be reset by the intervening item to the extent that it lacks common attributes with the prime. Deacon et al. found that the RVF/LH evidenced priming in both the adjacent prime-target condition and the intervening item condition, while the LVF/RH showed priming only in the former.

This being the case, how should selective attention act to differentially modulate semantic processing between the hemispheres? If we accept the above model of semantic structure, then answers to this question depend upon the capacity for attentional control of the left and right brain. In general, any mechanism that acts to dampen spreading activation should only be effective in inhibiting processing in the LH, as only

LH priming is based upon spreading activation. Before listing the specific hypotheses for the new experiments, we will review some of the evidence about the nature of attention, and what behavioral and ERP studies have indicated about the relationship between selective attention and semantic processing.

What is Attention?

Just as with semantic memory, attention is such a commonly used term, that it is often inadequately defined within any one study. Näätänen (1992) highlights two subtypes in his lucid discussion of the concept of attention: "selective attention," and "directed thinking." The former is what is most commonly thought of as attention, that is "withdrawal from some things in order to deal effectively with others," "taking possession of the mind, of clear and vivid form, of one out of what seem several simultaneous possible objects or trains of thought" (James, 1890, p. 27 in Näätänen, 1992). While these are both key parts of William James' classic definition of attention, a subtle distinction may be found within it, such that selective attention implies a filtration of a sensory signal, and directed thinking implies the modulation of activation levels of internally represented information. The current study will involve both of these aspects of attention, in that selection based on color information should 1) enhance and/or attenuate sensory signal strength relatively early on (Heinze et al. 1994; Waldorf et al., 1993; Harter & Salmon, 1972), and 2) should mark the information as "to-be-kept-from-consciousness," what some have called an "ignore tag" (Tipper & Driver, 1988). Evidence for these predictions comes from both behavioral and cognitive neuroscience studies, with the later offering more specific information about the temporal sequence of selection.

The seminal work in this area was carried out by Posner & Snyder (1975), and Neely (1977) (see Neely, 1991 for a review). Neely (1975) used category names as primes and a mixture of associatively and/or categorically related targets. He found that at 250 msec SOAs, only positive semantic priming occurred, such that targets preceded by related primes were responded to more quickly than those with an unrelated antecedent word. At a 2000 msec SOA, unrelated stimuli gave rise to inhibition in the form of response slowing relative not only to the related stimulus targets, but also to a neutral prime condition (X's). The critical factor in determining inhibition, as revealed over a series of replications, was the degree to which subjects could generate semantic expectancies about the target (den Heyer, 1985; Favreau & Segalowitz, 1983; Lorch et al., 1986).

Lateralized Behavioral Studies of Semantics and Attention

Burgess & Simpson (1988) used a visual half-field presentation technique to assess the relative contributions of the RH and LH to automatic versus controlled priming effects. The prime stimuli in this single word study were semantically ambiguous, polysemous nouns, such as "BANK," followed by either a more (MONEY) or less (RIVER) common associate as the target. Words were presented at SOAs of either 35 or 750 msec. At the shorter SOA, both hemispheres demonstrated significant priming for both the dominant and less frequent prime-target relationships. At the long SOA, however, the RVF/LH showed facilitation for the frequent meaning and inhibition for the less frequent, while the LVF/RH showed smaller effects for the frequent meaning, and relatively larger ones for the subordinate meaning. Burgess and Simpson interpreted their results as evidence that only the LH is capable of active suppression, and only after enough of a delay for attentionally based processes to become active. More recently, Faust & Gernsbaucher (1996) found parallel results in a sentence priming paradigm. They, too, argued that this phenomenon suggests that the RH and LH handle semantic selection in qualitatively different ways. In support of this, Chiarello, Senehi, & Nuding (1987) found that the LVF/RH evidenced greater or equivalent priming than the RVF/LH when the proportion of related to unrelated prime-target pairs was low, thus discouraging the use of controlled strategies, such as expectancy generation. When the relatedness proportion was raised, the same stimuli produced greater priming in the LH

Nakagawa (1991) examined the differences in the processing of three types of words by the left and right hemispheres. She used a semantic priming task in which the primes were either antonyms, remote associates, or unrelated words. Subjects were shown primes in either the LVF/RH, or the RVF/LH. Nakagawa found that targets that were presented directly to the left hemisphere showed early facilitation and late-developing inhibition. On the other hand, LVF/RH targets showed late-developing facilitation of strong (antonyms) and weak associates, and an apparent absence of inhibition.

Nakagawa then modified the priming task to include a pre-trial cue signaling the onset of the target word. This cue eliminated the differences in priming effects between the LH and RH. When the task was modified further to include close shadowing, all evidence of LH processing disappeared. These results lead Nakagawa to state that the inhibitory mechanism found in the left hemisphere is mediated by an anterior attention system. This system is thought to interact with a left hemisphere based representational network (Peterson, Fox, Posner, Minton, & Raichle, 1988; Petersen, Fox, Snyder, & Raichle, 1990). The finding of inhibition for weak associates in the left hemisphere leads us to suspect that the LH may be responsible for the controlled modulation of lexical/semantic activation.

Cognitive Anatomy of Attention

Critical to the earlier proposal of distinct early and late selection effects in a word processing task was the discovery of two separate, but interconnected attention networks (see Carr, 1992 for a review). The posterior attention system (PAS) involves posterior areas of lateral parietal cortex, portions of the superior colliculus, and the lateral thalamic pulvinar nuclei, and possibly areas of the cerebellum. This network is involved in the orientation of attention to relevant areas of space. Another network, the anterior attention system (AAS), is responsible for executive control, including formation of expectation based strategies (Carr, 1992). This broadly connected network consists of the medial prefrontal cortex including the cingulate gyrus and superior supplementary motor area, including connections to entorhinal, hippocampal, and primary motor cortex, as well as the basal ganglia. The interconnection of the cingulate cortex with prefrontal areas makes it a primary candidate for the structure concerned directly with the computation of lexical semantics (Carr, 1992; Goldman-Rakic, 1988).

The PAS was particularly important for the current experiments because subjects were required to rapidly locate stimuli that appeared, randomly, to the left or right of fixation. The PAS is directly involved in determining figure-ground organization, spatial relationships, and movement, reflecting its high concentration of magnocellular inputs from the periphery of the fovea. How is it related to color selection, a task which is primarily the purview of the parvocellular, foveal system? First, some color-sensitive cones do exist in the periphery. Otherwise, lateralized color-related tasks would be impossible. Second, an interaction between magnocellular and parvocellular pathways is highly influential on the timing necessary for normal, fluid reading (Breitmeyer, 1986). There is growing evidence that the magno-parvo interaction is mediated by attention (Shelley-Tremblay & Mack, 1999), and this is exemplified by its susceptibility to training (Solan, Larsen, Shelley-Tremblay, Ficarra, & Silverman, 2001; Solan, Shelley-Tremblay, Ficarra, & Silverman, under review).

The ability of the PAS to rapidly determine the exact position of a stimulus at a given point in time is necessary in order for the parvocellular system, with its terminations in AAS regions, to operate correctly. After the correct region in space has been isolated by the PAS, the subjects in the study described below should utilize the AAS in two different ways, at two points in time. First, the color information must be recognized rapidly (within early extra-striate cortex) and used to dampen the processing of the stimulus within the rest of the ventral processing stream. Second, the AAS should enhance the processing of the relevant stimuli at the level of lexical activation and suppress the processing of the irrelevant stimuli to keep them from impinging on consciousness. The novel proposition is that inputs from the LVF, with direct connections to the RH, should not show the effects of AAS inhibition. The current paradigm therefore predicts equivalent, or slightly larger LH than RH priming for attended words, and a lack of semantic priming effects in the LH for unattended words, as an indicator of inhibition. Additional support for these hypotheses comes from experiments that used event-related potentials as their primary dependent measure.

ERP Studies of Attention and Semantic Processing

ERPs and Spatial Selective Attention

If the PAS, which receives stimuli first, has reason to block the access of the AAS to incoming information, then the AAS would receive a greatly attenuated signal, if any at all. A study by Solan et al. (1998) provided evidence for this idea by demonstrating that individuals diagnosed with Reading Disability had a significantly reduced visual evoked potential component indicative of a deficiency in the magnocellular, and therefore, PAS system. When the PAS malfunctions, meaning processing for text suffers. Conversely, when the properly functioning PAS is directed away from some information in one region of space, it acts as a powerful screen against further processing of the irrelevant stimulus. Direct evidence of this comes from a study by McCarthy and Nobre (1993). They used a visual-half field technique not to explore hemispheric differences in semantic processing, but to designate one visual field as to-be-attended, and the other as to-be-ignored, alternately. McCarthy and Nobre framed their research in terms of the classic early versus late selection dichotomy, and predicted that their spatial selection cue would prevent any further processing of the irrelevant prime words, thereby eliminating any electrophysiological evidence of semantic priming.

Using vertically presented word and non-word stimuli that were separated by 5 degrees of visual angle on either side of fixation, McCarthy and Nobre found no evidence of an ERP repetition effect. This provided strong evidence, assuming a sensitive enough measure, that semantic processing is terminated before early levels of lexical activation when the stimuli are in an unattended spatial location. However, their conclusion that semantic processing, once initiated, requires attention in order to proceed does not follow from their results. Under conditions with such a wide spatial separation, spatial location is a powerful cue not only because of the extent to which the "attentional spotlight" is moved away from the irrelevant input, but because of the high level of discriminability of the relevant from the irrelevant channel (Hillyard & Münte, 1984). In the McCarthy and Nobre study, semantic processing for the unattended channel may never have received enough input to be initiated. The majority of behavioral studies that report masked semantic priming make it clear that the mask does not obliterate the initial sensory signal, but that it reliably impairs the access of the prime to consciousness (Greenwald, Draine, & Abrams, 1996).

Another study that used spatial selection, this time in the auditory modality, is that of Okita and Jibu (1998). They also used repetition of words in a variation on the classic dichotic listening paradigm (Triesman,1969). By factorially combining repetition priming (prime/target presentation) with attentional status (attended/unattended) they created four conditions that allowed a direct test of repetition priming as a function attending to the prime. The four conditions were attended prime followed by attended target (A/A), unattended prime followed by unattended target (U/U), attended prime followed by unattended target (A/U) and unattended prime followed by attended target (U/A).

Subjects were presented with word pairs simultaneously in both ears and attended to only one ear at a time on each block of trials, with half of the subjects listening in the order LRRL (L=left, R=right), and the others receiving RLLR. Okita and Jibu found a strong attenuation of the N400 in the A/A condition, but no significant differences between 1st and 2nd presentation in the U/A or U/U conditions. The N400 component produced by second presentations of words in A/U trials, however, was attenuated compared to first presentations in U/A trials. This effect just missed significance ($F(1,13) = 4.49$, $p < .06$). In spite of this, Okita and Jibu provided support for early selection theories, but acknowledged that early selection filters may attenuate and not prevent further processing of unattended stimuli (as per Triesman, 1969). Okita and Jibu state that because this experiment was auditory in nature, it is possible that the effect seen on A/U trials represents rapid switching of attention to the unattended channel. This argument is reminiscent of the unresolved debate begun when close shadowing of messages in dichotic listening tasks produced involuntary switching from the unattended to the attended ear in order to follow the semantic content of messages (See Johnson and Dark, 1986, for an insightful review of this debate).

ERPs and Color-cued Selective Attention

Otten, Rugg, and Doyle (1993) used color to define the relevant and irrelevant channels in a lexical decision task. Their study aimed to determine the extent to which unattended stimuli receive further processing beyond initial color selection. Stimuli were presented simultaneously in pairs slightly above and below fixation. They manipulated the factors of word repetition (first presentation/second presentation) and attentional status (attended/unattended) to produce the same conditions described as Okita and Jibu. Word and non-word stimuli were presented for 80 msec, with a 2.58 sec delay between pairs. These conditions yielded a reliable repetition effect for the A/A condition. This effect appeared as a sustained positivity with a maximum at electrode Cz relative to average waves obtained from first words, emerging at 400 msec and lasting until around 800 msec post-stimulus. The onset of this positivity was 150-200 msec later than in previous studies employing color as the attentional cue, possibly because of the high "filtering cost" of selecting relevant information that was presented in close spatial proximity to irrelevant information.

A smaller significant repetition effect emerged for the A/U condition. This effect may have been due to unconscious lexical or semantic activation, or, as suggested by Otten and colleagues, may have reflected heightened activation of the orthographic features of the attended word, such that the detection of even a few of these features during the presentation of the unattended target was sufficient to initiate further processing. No effect of repetition was found for the U/A or U/U conditions. In isolation, these findings do not support the hypothesis that unattended primes are processed beyond the level of initial selection, instead supporting an early selection model of attention (Broadbent, 1958). However, the results of their second experiment cast doubt on this view.

The second study used a spatial cue to provide the subject with prior information about the exact location of the relevant stimulus. The cue effectively defined the spatial position of the word; it lasted for 1586 msec, and offset abruptly only 150 msec before the target stimulus. As in the first experiment, repeated words in the A/A condition produced a large, Cz maximum positive shift in the region of the N400, which in this case onset at 300 msec. However, both the U/A and A/U conditions also produced small but significant repetition effects at the lateral electrodes. The usual repetition positivity was significantly reversed in the U/U condition, such that 2nd presentations produced a sustained negativity across the scalp. Otten *et al.* termed this the negative repetition effect. Otten, Rugg, and Doyle compared their inhibition effect to the negative priming observed in selective attention tasks using pictorial stimuli (Tipper, 1985; Tipper & Driver, 1988). In these studies, overlapping line drawings of novel shapes were presented in one of two colors, with only one color relevant at a time. The unattended shapes, when later attended, were responded to more slowly than the attended shapes, and more slowly than to a neutral condition composed of novel shapes. A similar phenomenon, the distractor suppression effect, was reported by Neill and Westberry (1987) who used the irrelevant information from the preceding trial in a Stroop task to serve as the relevant target information on the following trial.

Finally, Kellenbach & Mitchie (1996) conducted a study of color-cued selective attention and semantics using a lexical decision task. The stimuli consisted of 160 semantically related pairs and an equal number of unrelated pairs matched for word length and frequency. To these words were added 720 orthographically legal and pronounceable non-words. In the first experiment, subjects indicated whether the attended stimulus was a legal word by pressing one of two buttons on each trial. In the second experiment, subjects were required to make a button press only if they saw an attended non-word. Significant N400 priming effects were obtained, as evidenced by the prime ERP being more negative than both the target ERP and a control ERP elicited by orthographically legal non-words in the 350-600 msec window. These effects occurred in the A/A and A/U conditions of both experiments. Kellenbach and Mitchie concluded that the determining factor in activating semantic priming is attentional processing of the prime. Behavioral evidence of negative priming was obtained for the U/A condition of experiment 1 but was not replicated in experiment 2.

The Kellenbach and Mitchie study has several shortcomings. One is the use of a lexical decision task, which can sometimes be accomplished merely on the basis of a check of the lexical identity of the stimulus, without semantic-level processing. The N400 is also sensitive to task demands, in that it occurs most reliably on tasks when subjects must process the meaning of the word (Rugg, Furda, & Lorist, 1988). Another possible problem with this study is the requirement of an RT response to the targets, which causes an ERP known as the P300 to occur. The P300 is a large positive component that often overlaps the N400 and is known to be sensitive to post-lexical processes, in that it reflects stimulus classification processes for both linguistic and nonlinguistic stimuli. If the P300 were shifted in time as a function of stimulus relationship, then this shift could obscure some of the priming effects on the N400. The new study described below required a semantic relatedness judgment to a probe occurring well after the offset of the target, simultaneously ensuring deep processing and a diminished P300.

Selective Attention Effects (SAEs)

The efficacy of color as a selection cue has been established in several electrophysiological studies. In addition to the significant selective activation enhancements to relevant colored stimuli observed in PET studies (Corbetta et.al, 1990), numerous ERP studies have shown a color-selection "fingerprint" in cognitive processing tasks (Harter & Aine, 1984; Otten, Rugg, & Doyle, 1993; Mulders, Wijers, Brookhuis, Smid, & Mulder, 1994; van der Stelt, van der Molen, Boudewijn Gunning, & Kok, 2001). This fingerprint consists of a series of typically occurring, but highly task sensitive, positive and negative components in the averaged ERP record. The color selection components are formed by subtracting irrelevant from relevant stimuli, and can consist of 1) an early frontal positivity in the 150-300 msec range, referred to as the frontal selection positivity (FSP); 2) a posteriorally maximum negativity in the same approximate time range called the selection negativity (SN).

In the present study, the addition of a semantic processing requirement creates the potential for a large and potentially confounding overlap of later SAEs and the N400. As noted above, the latency and amplitude of the P300 may vary with task demands and confound the interpretation of N400 (Deacon et al., 2000). The paradigm used in this study attempts to greatly reduce the size of the P300 by having subjects make a judgement and subsequent behavioral response only to a probe word (DOG-CAT-FLEAS: "Is 'fleas' related to 'dog'?")

In light of these issues, it was expected that the best measures of effective color selection would be found in the earlier components, the FSP and SN. Only the FSP has been reported as occurring reliably in the study that shares the most experimental parameters with the present study (Kellenbach & Mitchie,1996). It was therefore predicted that SAEs would demonstrate an FSP, possible SN, and that later effects of attention would interact with those of semantic processing.

Original Experiments: Summary of Design and Hypotheses

Design Summary

Both of the present studies were color-cued selective attention paradigms that required subjects to maintain central fixation while processing the meaning of the relevant stimuli that appeared randomly in either the LVF or RVF. Experiment 1 studied the effects of attention on the N400 as an index of lexical/semantic processing when both prime and target were attended or unattended. The second experiment assigned relevant status to either the prime or target, with the other designated as irrelevant, replicating and extending Kellenbach & Mitchie (1996) using a between subjects design on the factor of attentional status as same or mixed for any one trial. Both studies employed a long SOA in order to be able to observe the action of attentionally based priming mechanisms.

Hypotheses

1. We predicted that lateralized presentation of associatively and categorically related prime-target pairs that were explicitly constructed to have a high degree of association and semantic feature overlap will produce reliable semantic priming in both hemispheres when attended, thus replicating an earlier study from our laboratory (Deacon et al., in preparation).

2. It may be that the findings of no priming or the suggestions of inhibition from the U/A and U/U conditions in the ERP studies just reviewed actually represent an additive mixture of facilitative RH and inhibitory LH processing, and that if the behavior of the hemispheres were assessed independently it would become apparent that both attentional selection and automatic semantic processing can occur simultaneously. Specifically, the LVF/RH should evidence reliable semantic priming in the N400 region regardless of the attentional status of either prime or target.

3. The RVF/LH should show significant priming only in the condition in which the prime is attended (A/A), and should show no priming in the U/U condition. This should occur

because stimuli that are processed up to the semantic level regardless of their attentional status in the LVF/RH are designated as irrelevant and suppressed in the LH.

II. Experiments

II.1 Experiment 1

Methods

Subjects

Seventeen normal, healthy young adults (9 males, 8 females) participated in the study. Subjects were recruited from posted advertisements on the college campus, or from introductory Psychology classes. They were paid a small honorarium, and given extra credit in the introductory course when applicable. Of the 17 subjects, 5 were excluded from the analyses due to low numbers of accepted trials, low accuracy, or noisy data. The mean age of the 12 remaining subjects was 28.2 years for the females (n = 5; SD = 2.6), and 26.6 years for the males (n = 7; SD = 5.3), with an overall average age of 27.4 years (SD = 4.0), and a range of 19 to 36 years. All subjects were monolingual, native speakers of American English. Subjects' exposure to other languages was diverse, with classroom instruction and limited travel in other countries, but no subject reported mastery of, or more than five years of instruction in any other language. English was the only language spoken in the home by both parents, for all subjects, and no subject reported a history of foreign language exposure before 5 years of age. Only strongly right handed individuals were solicited. Subjects were deemed to be right handed, with a mean Laterality Quotient (LQ) of 97.9 (SD = 6.9), according to the Edinburg Handedness Inventory (Oldfield, 1971). All but one subject, who had a score of 75%, had an LQ of 100%. LQ was measured by responses to questions about hand preferences for common activities. A brief assessment of foot and eye preference, and familial sinistrality/dextrality was included as well. No subject reported maternal or paternal sinistrality, nor did any subject report histories of any medical or neurological disorders or learning disabilities. No subjects reported taking medications. All subjects reported normal or corrected to normal vision, and far point acuity was assessed at 10 feet with a Graham Field eye chart. All subjects tested in this manner evidenced 20/20 vision.

Materials

The stimuli consisted of concrete English nouns. They were presented as triplets in the sequence: prime (S1), target (S2), question mark, and probe (S3). Pairs of words (S1/S2) were selected such that they were related categorically (Battig & Montigue, 1969), and associatively (Nelson et al., 1998) and shared common features (DOCTOR-NURSE). The targets were also matched for word length and frequency (See Table 1). We designed stimuli in this way based on previous ERP research suggesting that all of these aspects are necessary in order to produce reliable semantic priming in both hemispheres (Deacon et al., under review; Deacon et al., in preparation). There were 240 pairs of this type and an additional 240 semantically unrelated pairs (TRUCK-SPONGE). The question mark alerted the subjects of the coming probes, and provided temporal separation between the critical target (S2) and the probe (S3) to which a judgment of semantic relatedness was made. The probe (S3) was either related to the prime or the target (50% of trials), or to neither the prime nor the target (50% of trials).

The prime and target were shown in either bright red or bright blue against a white background. The question mark appeared in black on all trials. The stimuli were presented in ten blocks of 96 triplets per block, with half of the blocks labeled as "red-relevant,"and the other half as "blue-relevant." The critical S1 and S2 were identical in color on any given trial within a block, so that they were both to-be-attended or to-be-ignored. All of the blocks of one color were presented together, followed by the blocks of the other color, with the initial relevant color counter-balanced across subjects.

To ensure that the color of the target could not be predicted from the color of the prime, and thus promote selective attending, we created 240 filler trials where S1 was presented in one color and S2 in the other. The words were 2 to 12 characters in length ($\bar{x}$=5.62 letters; 4 cm) and 1 cm high. They were centered at 4 ° of visual angle to the right or the left of a fixation mark (+) that appeared in the center of a 15 in. color CRT monitor driven by an IBM-compatible 386 computer. Subjects were seated at a distance of 67 cm from the screen, with head position measured at the beginning of each block of trials. At this distance, the words subtended .86° of visual angle vertically, and an average of 3.42° horizontally. The stimuli were shown one at a time for 185 msec, with a 1 sec stimulus onset asynchrony (SOA) between all stimuli within the trial. There was an interval of 2.5 sec between the onset of the probe and the onset of the next S1. Subjects were given a 2.4 sec window in which to respond.

Procedure.

Subjects were tested individually, with a break between each block. They were seated in a comfortable chair in a dimly lit room. The subjects were instructed that they were going to see words that would appear one at a time, either to the right or left of a central fixation mark. They were told that they must maintain fixation upon the mark (+) at all times during the experiment, except during breaks. They were told to expect two words, followed by a question mark, and then a third word. Each subject was informed of the relevant color was for that block, either red or blue. They were instructed to attempt to process the meaning of the relevant words only.

They were instructed that the first two words would be in either red or blue, in no particular order. The third word would always be in the relevant color as a reminder that they should process only the relevant words. Upon presentation of the third word, they were to decide whether the probe word was related in meaning to the last relevant word that had been presented within that trial. For instance, if DOG was presented in red on a red-relevant block, followed by ROCK in blue, then the question mark, and then CAT, always in red, the subject would recall that DOG was the last relevant stimulus, and press the left mouse button with their right index finger. In the case of an unrelated probe, subjects pressed the right mouse button with their middle finger. On trials in which subjects were instructed to ignore both S1 and S2 (on filler trials in the second experiment) they were to respond "unrelated" to the probe (S3). Figure 5 illustrates a typical red-relevant trial with a related S1 and S2, and a related S3.

Eye Movement Calibration and Training

Prior to presentation of the experimental trials, subjects were presented with an eye movement monitoring and training task. A fixation cross appeared for 250 msec on the monitor, followed by a pause of 250 msec, and then words appeared 4 degrees to either the left or right of fixation. The words appeared for 185 msec, and subjects were instructed to move their eyes and track the occurrence of each word so that they could read it normally, while otherwise remaining still. In this manner, we produced a record of the amplitude and morphology of each subject's eye horizontal eye movement that was later used as a basis for identifying eye movement artifacts for removal from the continuous EEG file.

Following this phase, subjects were again shown lateralized words, but this time they were instructed to attempt to read the words to themselves while maintaining fixation on the central mark. The horizontal EOG was monitored, and if any deviation from the fixation mark occurred, subjects were told, "Keep your eyes on the mark." The training phase was repeated until the subjects could comfortably maintain a central fixation while reading. Also, the single word "eye" was used as a reminder to subjects during the later training phase, as well as during the main ERP task, if an occasional eye movement occurred. In this way, eye movements were kept to a minimum.

EEG Recording

The electroencephalogram (EEG) was recorded from 18 standard 10-20 system scalp locations including FP1, FP2, Fz, F3, F4, Cz, C3, C4, T3, T4, Pz, P3, P4, T5, T6, O1, Oz, and O2, referenced to the nose. Electrodes placed on the supraorbital ridge and inferior canthus of each eye were used to monitor vertical and horizontal electroocculogram (EOG). The EEG and EOG were sampled at 547 points over a 1200 msec sweep, which began 200 msec prior to stimulus onset. Recordings were filtered on line with a band pass of .1 to 35 Hz, and off line with a 20 Hz digital low pass filter. Electrical artifacts, including horizontal eye movements, were removed from the raw EEG data using a process of visual inspection. Baseline correction was performed in relation to the average ERP activity in the 200 msec preceding the onset of the critical stimulus (S2). Following baseline correction, trials were rejected on which EEG or EOG activity exceeded plus or minus 50 μV; or 60 μV for subjects with slightly noisier recordings. Single trials were then sorted and averaged according to attentional status (relevant or irrelevant), whether the word had been primed or unprimed, and whether the words had appeared in the right (RVF) or left (LVF) visual field.

Data Analysis

Expected Components

Selective Attention Effects

SAEs were quantified through mean area measurements, and analyzed for significance and topographical differences using the repeated measures analysis of variance technique, with the Greenhouse-Geisser correction applied where appropriate.

The SAE windows were determined through visual inspection of the unsubtracted and subtracted (attended minus unattended) grand averaged waveform. FSP and the SN were expected to occur in the 150 to 300 msec range, and thus were quantified as the largest frontally distributed positive (FSP), or posteriorally distributed negative (SN) peak within this window.

The N400

The expected component of interest was the N400. This component was identified as an N400 wave because of its sensitivity to semantic priming, peak latency, and parietal-occipital maximum. The N400 component was defined as the largest negative peak in the unattended waveform that was observed between 300 and 500 msec post stimulus (S2) onset based on inspection of the individual and group averaged waveforms (Kutas & Hillyard, 1984; 1989). The N400 mean amplitude was computed automatically by Neuroscan software, and the mean amplitudes for the measurement windows (in Results) were submitted to the repeated measures analysis of variance technique, with the Greenhouse-Geisser correction applied where appropriate.

Results

Behavioral data

Subjects were accurate on the probe relatedness judgement task ($\underline{\bar{x}}$ = 88.61%, SD = .04), indicating that they were paying attention to the task well enough to ensure performance near a ceiling level. Reaction times to probes were not computed, as they were not diagnostic of either attentional status or semantic processing performance.

ERP data

SAEs

The SAEs were examined separately for both the prime (S1) and target (S2) stimuli in order to determine whether attention acted differently (regardless of actual stimulus color) on the first stimulus to be selected in comparison with the second. The unattended waveforms for primed and unprimed stimuli were averaged and compared with the equivalent averaged attended waveforms separately for each visual field.

FSPs

S1

Figures 6 and 7 display the unsubtracted irrelevant and relevant waveforms for the RVF/LH and LVF/RH S1 stimuli, respectively. Figure 6 presents 5 electrodes (Fp1, Fp2, F3, Fz, and F4) that demonstrated the maximum attention-related positive shift based on inspection of the grand averaged waveforms. No attention-related positivity was present in the LVF/RH. In order to quantify the effects of attention, mean amplitudes were computed for the unsubtracted data for the displayed electrodes in the windows of 160 to 250 msec for the LVF/RH and 170 to 260 msec for the RVF/LH. For the RVF/LH, an ANOVA was carried out with the factors of Attention (Attended/Unattended) and Electrode (Fp1, Fp2, F3, Fz, and F4) that yielded a significant main effect of Attention ($F_{(1,11)} = 8.012$, $p = .016$). In an ANOVA with the same factors, no reliable effect of attention was obtained for the LVF/RH ($F_{(1,11)} = 2.822$, $p = .118$). No interactions were present with electrode in the S1 analyses. An FSP was present for the LH, but not for the RH for the S1 stimuli.

S2

Figures 8 and 9 display the unsubtracted irrelevant and relevant waveforms for the RVF/LH and LVF/RH S2 stimuli, respectively. As with the S1 stimuli, an attention-related positive shift was apparent for the RVF/LH, but a smaller LVF/RH positivity is present for S2. The same electrodes and time windows as in the S1 analyses were used to produce mean amplitude data that was subjected to separate ANOVAs for the RVF/LH and the LVF/RH. For the RVF/LH, a significant main effect of Attention ($F_{(1,11)} = 6.913$, $p = .023$) emerged, providing evidence of an LH FSP. As in the S1 analysis, no effect of attention appeared for the LVF/RH ($F_{(1,11)} = 1.654$, $p = .225$).

SNs

S1

Figures 10 and 11 display the unsubtracted irrelevant and relevant waveforms for the LVF/RH and S1 RVF/LH stimuli, respectively. Figure 10 presents 8 electrodes (T5, T6, P3, Pz, P4, O1, Oz, and O2) that demonstrated the maximum attention-related negativity based on inspection of the grand averaged waveforms. For the RVF/LH

(Figure 11), only electrodes T5, P3, and O1 evidenced any attention-related negativity. In order to quantify the effects of attention, mean amplitudes were computed for the unsubtracted data for the displayed electrodes in the windows of 160 to 250 msec for the LVF/RH and 170 to 260 msec for the RVF/LH. For the LVF/RH, an ANOVA was carried out with the factors of Attention (Attended/Unattended) and Electrode (T5, T6, P3, Pz, P4, O1, Oz, and O2) that yielded a significant main effect of Attention ($F_{(1,11)} = 5.355$, $p = .041$). In an analysis with the same factors and levels, no significant effect of attention was obtained for the RVF/LH ($F < 1$). No interactions were present in the S1 analyses. Thus, an SN was present for the RH, but not for the LH for the S1 stimuli.

S2

Figures 12 and 13 display the unsubtracted irrelevant and relevant waveforms for the LVF/RH and RVF/LH S2 stimuli, respectively. As with the S1 stimuli, an attention-related negative shift was apparent for the LVF/RH, but not for the RVF/LH. The same electrodes and time windows as in the S1 analyses were used to produce mean amplitude data that were subjected to separate ANOVAs for the LVF/RH and the RVF/LH. For the LVF/RH, Attention proved a significant factor ($F_{(1,11)} = 6.211$, $p = .030$). Like the S1, the S2 evidenced no SN for the RVF/LH ($F < 1$).

N400 Effects

General

The grand averaged ERPs were formed for the primed and unprimed waves separately for each attentional and visual field condition (See Figures 14,15,16,17). Across conditions, several morphological features were consistent, including an occipitally maximal P1, N1 series of deflections typically associated with stimulus feature detection and processing in visual ERP studies (Mangun & Hillyard, 1987). For the unattended conditions, an N400 was present that was more positive in the primed condition than the unprimed in the LVF/RH (Figure 14), and more negative in the primed condition than the unprimed in the RVF/LH (Figure 15). For the attended conditions, the primed waves were more positive than the unprimed waves for both visual fields of presentation (see Figures 16 and 17).

We evaluated the hypothesis that attention would differentially modulate the occurrence of semantic processing as a function of visual field. In order to test this, the mean amplitudes of the N400 component were subjected to a repeated measures ANOVA. The ANOVA contained the within subjects factors of Visual Field (LVF x RVF), Attention (Attended x Unattended), Priming (Unprimed x Primed), and Electrode (Fp1, Fp2, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2). This analysis yielded a significant effect of priming ($F_{(1,11)} = 11.169$, $p = .007$), and a significant interaction of Visual Field, Attention, and Priming ($F_{(1,11)} = 15.514$, $p = .002$). In order to explore the main three-way interaction above, separate ANOVA's were conducted for each hemisphere.

LVF/RH N400 Effects

Attended

For the LVF/RH attended condition, a broadly distributed N400 priming effect is visible in the grand averaged waveform (see Figure 16) in the time window 360 to 560 msec post S2. In an ANOVA on the mean amplitudes from the above window with the factors of Priming (Primed/Unprimed) and Electrode (Fp1, Fp2, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2) a main effect of priming emerged ($F_{(1,11)}$ = 6.442, p = .028, Eta^2 = .369). An inspection of the grand average reveals an occipito-parietal maximum for the priming effect. When only the occipital and parietal electrodes were included, the effect increased ($F_{(1,11)}$ = 7.026, p = .023, Eta^2 = .390), and it increased further with only the occipital electrodes ($F_{(1,11)}$ = 12.789, p = .04, Eta^2 = .538). The square root of Eta^2 (Eta), in this case .68, indicates the presence of a large priming effect in the LVF/RH attended condition in the measured window (Cohen, 1988).

Unattended

For the LVF/RH unattended condition, a broadly distributed N400 priming effect was visible in the grand averaged waveform (see Figure 14) in the time window 360 to 560 msec post S2. In an ANOVA with the factors of Priming (Primed/Unprimed) and Electrode (Fp1, Fp2, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2) a main effect of priming emerged ($F_{(1,11)}$ = 4.873, p = .049, Eta^2 = .307). An inspection of the grand average reveals an occipital maximum for the priming effect. When only the occipital electrodes were included, the effect increased ($F_{(1,11)}$ = 5.349, p = .041, Eta^2 = .327). As in the attended condition, this is a large effect (Eta = .57).

RVF/LH N400 Effects

Attended

For the RVF/LH attended condition, an N400 priming effect is readily apparent at all electrodes in the window 330 to 530 msec (See Figure 17). In order to quantify this effect, mean area measurements from the 330 to 530 msec window were subjected to an ANOVA with the factors of Priming (Primed/Unprimed) and Electrode (Fp1, Fp2, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2), which yielded a significant main effect of Priming ($F_{(1,11)} = 7.939$, $p = .017$, $Eta^2 = .419$). No Priming by Electrode effect emerged ($F =_{(2.3,25.4)} = 2.363$, $p = .108$ {corrected with GG}), but this value was suggestive of the visually apparent occipito-parietal maximum observed in Figure 17. When occipital and parietal electrodes only were included in the ANOVA model, the main effect increased ($F_{(1,11)} = 9.246$, $p = .011$, $Eta^2 = .457$).

Unattended

For the RVF/LH unattended condition, the primed wave was more negative than the unprimed wave 330 to 530 msec, suggesting a reversal of the priming effect (see Figure 15). This reversal had a broad distribution, as indicated by the absence of a Priming by Electrode interaction in a repeated measures ANOVA with the factors of Priming (Primed/Unprimed) and Electrode (Fp1, Fp2, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2). The reversed priming was not significant ($F_{(1,11)} = 1.430$, p

= .257, $Eta^2 = .115$), indicating the presence of no significant effect for this condition. The reversal effect was moderate (Eta = .34).

Summary of ERP Effects

SAEs

The RVF/LH demonstrated significant FSPs, while the LVF/RH demonstrated significant SNs.

N400s

The RVF/LH showed significant priming for the attended condition only, while the LVF/RH demonstrated significant priming regardless of attentional status. For the purpose of comparison, the Oz electrode for each condition in Experiment 1 is displayed in Figure 18.

Discussion of Experiment 1

Both attended and unattended conditions produced semantic priming in the LVF/RH. In contrast, only the attended condition evidenced significant priming in the RVF/LH. This provides support for each of the three hypotheses outlined above. In regards to hypothesis 1, this experiment provides evidence that the RH can produce semantic priming effects that are comparable to those of the LH (attended) in size and distribution. This suggests that the RH has access to semantic information (See Deacon et al., 2003), that is qualitatively more than quantitatively different than the LH.

Hypothesis 2 predicted priming for the RH irrelevant condition. The finding of significant N400 priming in the RH, even when both prime and target were ignored, makes it possible that either: 1) the RH is not capable of selective attention, or 2) the stimuli did undergo selection on the basis of color, but no suppression of information at the semantic level occurred for the irrelevant stimuli. Two findings argue against the first interpretation. First, the critical stimulus showed evidence of both a significant frontal and posterior early effect of attention. Second, the presence of a significant disruption of semantic priming in only the LH unattended condition makes it unlikely that a failure of attention can account for the results of this experiment.

The presence of significant SNs for S2 in the LVF/RH condition was not predicted. The combination of SAEs and irrelevant condition priming raises the question of why the RH system would mark stimuli as irrelevant, and then fail to utilize this information. One possibility is that all irrelevant stimuli are marked as to-be-ignored by an early system sensitive to the physical features, but that the two hemispheres utilize this information differently. Such an early system has been proposed by Tipper & Driver (1988) who theorized that "ignore tags" are appended to irrelevant stimuli that allow them to receive further processing without entering consciousness and using up limited attentional resources. Thus SAEs may be electrophysiological correlates of the process of stimulus relevancy designation, as opposed to simply a relative dampening or enhancement of stimulus processing.

Hypothesis three, that the LH should show priming for attended, but not for unattended stimuli, was supported. The grand average waveforms for the LH U/U condition resemble somewhat those of Otten, Rugg, & Doyle (1993) for the comparable condition in their second experiment. Our waves showed a small reversal of the priming effect, but this proved not significant. In conjunction with the reliable FSPs, these results suggest the *operation of early selection in the LH.*

In support of the model of Deacon et al. (submitted), the mixture of facilitation and no priming in the LH is consistent with a local network that operates on the basis of spreading activation. In addition, the finding of RH priming regardless of attentional status of the prime and target is consistent with a conceptualization of the RH as a distributed network in which an attentional mechanism that acts by dampening spreading activation would be ineffective.

II.2 Experiment 2

The critical question yet to be answered was whether an ignored prime or target only would be sufficient to produce the disruption of priming in the LH seen in Experiment 1. A second experiment was conducted with only the prime *or* target appearing in the relevant color. Such a manipulation mirrors the design of Kellenbach & Mitchie (1996), Otten, Rugg, & Doyle (1993), and Okita and Jibu (1998), who included a mixed attention condition as a within subjects factor. If an ignored prime alone yields a lack of priming, then the results of previous authors who used central presentation (Kellenbach & Mitchie, 1996) would be replicated. If an ignored prime alone produces no priming this will indicate that the locus of the disruption is in a dampening of spreading activation, such that the representation of the target cannot receive any automatic increase in its resting activation level. If no priming occurs only for ignored targets, then it is more likely that the locus of the suppression is in the active inhibition of the target's representation. No priming in an LH A/U condition would indicate that attention was able to block the activation of the target's semantic representation, despite the fact that it had just been raised by the prime, providing strong support for early selection. No priming in the LH with only an ignored target would indicate that attention was blocking semantic processing.

Methods

Subjects

A group of fifteen subjects (6 females, 9 males), some of whom had participated in Experiment 1 at least 6 months prior, participated in Experiment 2. Of these, 5 were excluded due to low trials, noisy data, or poor accuracy. Of the remaining subjects, the mean age was 26.4 (SD = 1.9) years for the males (n = 5), and 21.4 (SD = 2.1) for the females, with an overall age range of 19 to 29 years. Their mean handedness quotient was 98.0% (SD = 4.0), indicating strong dextrality. Two subjects had 90% L.Q.'s, and the rest had 100%. They were identical to the subjects in Experiment 1 in terms of no general medical, psychological, neurological, or learning problems.

Materials and Procedure

All aspects of the materials and procedure were identical to Experiment 1, with the exception of the assignment of color to the words. Whereas Experiment 1 always paired two relevant or two irrelevant words, Experiment 2 always paired a relevant and an irrelevant within trials. Thus the critical second word was, if relevant, preceded by an irrelevant prime, and if irrelevant, preceded by a relevant prime. The fillers trials were always presented as either both relevant, or both irrelevant. In the case of two irrelevant stimuli on half of the filler trials, subjects were to respond "unrelated" by pressing the right mouse button.

Results

Behavioral Data

The mean accuracy for the critical trials on the probe relatedness judgement task was 80.4%, which is significantly greater than chance (50%) performance ($T_{(9)} = 13.589$, $p < .001$). This task was also significantly harder ($T_{(20)} = -3.333$, $p = .003$) than the critical trial performance on the probe relatedness task in Experiment 1. This is intuitively understandable when one considers that the probe task requires a retrospective memory search. The subjects were searching for semantic relatedness while retrieving the correct prior word, which was sometimes strongly related to the to-be-ignored stimulus.

ERP Data

The ERP waveforms are comparable to those of Experiment 1, before the N400 region, exhibiting an occipitally maximal N1, P1 series of deflections in the earlier portion of the sweep. A relatively large, broad negative deflection with an approximate peak latency of 450 msec was apparent, which was identified as the N400 based in the criteria described above, was evident for all unprimed conditions with its condition-matched primed waveform showing a relative positivity, except for the RVF/LH UA condition, which showed no priming effect. The grand average waveforms for the Experiment 2 N400 priming effect are displayed in Figures 28, 29, 30, and 31.

SAEs

The FSPs for Experiment 2 are shown in Figures 19, 20, 21, and 22. As in Experiment 1, the waveforms are shown with primed and unprimed conditions collapsed. No significant SN's appeared in this experiment, but the waveforms are presented for comparison purposes in Figures 23, 24, 25,and 26.

FSPs

S1

The mean amplitudes from the window 160 to 230 msec were calculated for the unattended and attended waveforms for both visual fields. These time windows were used for both the LVF and RVF FSP and SN analyses. For the LVF/RH, an ANOVA with the factors of Attention (Attended and Unattended) and Electrode (Fp1, Fp2, F3, Fz, F4) was carried out that indicated the presence of a significant FSP ($F_{(1,9)} = 6.753$, $p = .029$, $Eta^2 = .429$). This attention-related effect is displayed in Figure 19. A similar result was obtained in an equivalent ANOVA for the RVF/LH data that showed the presence of a significant main effect of Attention ($F_{(1,9)} = 8.186$, $p = .019$, $Eta^2 = .476$). The RVF/LH waveforms are shown in Figure 20.

S2

For the LVF/RH, frontal effect of attention emerged for the critical stimulus in this Experiment ($F_{(1,9)} = 7.307$, $p = .024$, $Eta^2 = .448$) in an ANOVA with the same factors and levels as in S1. The LVF/RH S2 FSP is displayed in Figure 21. An equivalent ANOVA on the RVF/LH data (see Figure 22) produced the largest effect of Attention ($F_{(1,9)} = 8.588$, $p = .017$, $Eta^2 = .488$).

*SN*s

No posterior attention-related negativity occurred in Experiment 2 for either stimulus.

N400 Effects

General

The N400 exhibited a parito-occipital maximum, that appeared to vary slightly by condition. For the RVF/LH, the measurements for the N400 window (410 to 530 msec) were based on the effect seen in the AU condition, as none was apparent in the UA condition. For the LVF/RH, the same window (410 to 530 msec) was appropriate for the AU condition, but the UA condition exhibited a markedly shorter duration effect (450 to 500 msec). As in Experiment 1, we evaluated the hypothesis that attention would differentially modulate the occurrence of semantic processing as a function of visual field. Therefore, the mean amplitudes of the N400 component were subjected to a repeated measures ANOVA. The ANOVA contained the within subjects factors of Visual Field (LVF x RVF), Attention (Attended x Unattended), Priming (Unprimed x Primed), and Electrode (Fp1, Fp2, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2). This analysis yielded a significant effect of priming ($F_{(1,11)} = 8.081$, $p = .019$., Eta2=.473), but no significant interaction of Visual Field, Attention, and Priming ($F < 1$).

In order to explore the interaction of priming and electrode above, an additional ANOVA was carried out on scaled data. Scaling was accomplished by a division of the amplitude values at each electrode within any given condition by the largest single value at any one electrode for that condition. The effect of this scaling is to allow for a comparison of the priming effects unconfounded by gross differences in the amplitude of any one condition (Deacon et al., 2000, Deacon et al., 1991, Deacon et al., 1995). This ANOVA yielded a significant interaction of Priming and Electrode ($F_{(2.341,21.065)} = 4.477$, $p = .02$ GG), indicating that the priming effect varied across the recording sites. Follow-up analyses revealed that the effect was not significantly larger at any one electrode ($p = .05$). The topography of Experiment 2, collapsed across Visual Field and Attention (which were not significant factors) is represented in Figure 27. Here, an occipito-parietal maximum is clearly visible.

Additional analyses were undertaken, as per Experiment 1, to examine the effects of semantic priming between the different attentional combinations and visual fields.

LVF/RH N400 Effects

S2 Unattended

For the LVF/RH AU condition, a posteriorally distributed N400 priming effect is visible in the grand averaged waveform (see Figure 28). In an ANOVA on the mean amplitudes from the above window with the factors of Priming (Primed/Unprimed) and Electrode (P3, Pz, P4, O1, Oz, and O2) a main effect of priming emerged ($F_{(1,9)} = 6.168$, $p = .035$, $Eta^2 = .407$), that is considered large according to the method of Cohen (1988), ($Eta = .64$). No interactions were present.

S2 Attended

For the LVF/RH UA condition, an N400 priming effect with a short duration and a posterior distribution is visible in the grand averaged waveform (see Figure 29). An ANOVA with the same factors as above produced a main effect of priming ($F_{(1,9)} = 7.008$, $p = .027$, $Eta^2 = .438$). No interactions were present.

RVF/LH N400 Effects

S2 Unattended

For the RVF/LH AU condition, a broad N400 priming effect is present (See Figure 30). An ANOVA was run with the factors of Priming (Unprimed x Primed), and Electrode (Fp1, Fp2, F3, Fz, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2), and the resulting effect of Priming was significant ($F_{(1,9)} = 14.745$, $p = .004$, $Eta^2 = .621$). In comparison with the other conditions, when just the parietal and occipital electrodes were included, the effect size reduces slightly ($F_{(1,9)} = 11.857$, $p = .007$, $Eta^2 = .568$), again suggesting a more broad distribution.

S2 Attended

For the RVF/LH UA condition, the primed wave was not different from the unprimed wave (see Figure 31). This was confirmed in an ANOVA equivalent to that completed in the LVF/RH UA condition, which yielded no significant effect of Priming ($F_{(1,9)} = 1.5$, $p = .248$).

Summary of ERP Effect for Experiment 2

Summary of Early Effects of Selective Attention (SAEs)

Every condition showed evidence of a significant FSP, but none of the SNs reached significance.

Summary of Interaction of Attention with Semantic Processing (N400)

For the RVF/LH, significant priming emerged only in the AU condition, with the UA condition showing no effect. Semantic priming was present for both attentional conditions in the LVF/RH, with the UA condition actually showing a slightly larger effect than the AU.

Discussion

All three of the main hypotheses set forth in the introduction were born out in Experiment 1, with Experiment 2 serving to provide additional information about the locus of the disruption of priming (S1 or S2). The predicted pattern of LH failure of priming for unattended stimuli occurred in Experiment 1, and Experiment 2 suggested that it is the ignoring of the prime as opposed to the target that accounts for this LH localized attention effect.

Attentional Mediation of Priming Effects

As regards Hypothesis 1 that priming would be found in both hemispheres, the finding of semantic priming in the LVF/RH is suggestive of the presence of a semantic network with sufficient complexity to process the majority of the large number of common English nouns used as stimuli (See Appendix A). The current stimuli, which were expressly designed to share semantic features, succeeded in producing RH semantic priming. The results also suggest that whatever system is in operation in the RH, it is largely insensitive to the effects of selective attention on semantic-level processing, thus providing evidence for Hypothesis 2. The model of Deacon et al. hypothesized the existence of a complete RH semantic system, but that is organized according to a distributed feature network. While theoretically possible, no version of Masson's (1995) distributed semantic model has been proposed that postulates how attention would act to disrupt semantic priming in such a system. The finding of priming regardless of attentional status is consistent with the idea of a distributed system in which attention does not play a role.

As for the other part of Hypothesis 1, the RVF/LH results of both Experiments 1 and 2 are in line with the Deacon et al. model, in that the LH showed semantic priming to categorically and associatively related stimuli. As regards Hypothesis 3, the current results are inconclusive on the issue of whether the LH UU and UA lack of priming is due to active suppression at the semantic level, or more effective early selection in the LH that prevents semantic processing from being initiated. However, it should be noted that it is unlikely that the lack of priming observed in the LH UU and UA conditions represents a simple failure of priming in the LH. The LH priming in the AA and AU conditions make that hypothesis untenable. In addition, examination of the SAEs does not suggest that the LH was somehow more effective in early selection overall in that they are of approximately equivalent amplitude and latency to the RH. Furthermore, the LH UU condition does show a reversed (albeit not significantly) priming effect that is reminiscent of the negative repetition effect demonstrated by Otten, Rugg, and Doyle (1993), which they interpreted as evidence of the active suppression of ongoing processing. Several mechanisms have been proposed that could explain the presence of attentional suppression.

The Deacon et al. (in press) model conceptualized the LH as an automatic spreading activation (ASA) network. Numerous studies have provided evidence for the notion of an inhibition effect localized to the semantic level (Tipper, 1985; Dagenbach, Carr, & Wilhemson, 1989; Barnhart, Glisky, Polster, & Elam, 1996). In one theory, spreading activation could serve to dampen the resting level of associated targets by an automatic process (Houton and Tipper, 1994) that is part of a general match/mismatch processing system. Houton and Tipper describe a model in which stimuli that contain features, such as color, that fail to match the "target," or task-relevant specification (red vs. blue) generate a mismatch response. This response serves to provide feedback to a gain control subsystem which has the result that the balance between facilitatory and inhibitory processes is shifted in the direction of inhibition. The inhibition would start within the subsystem responsible for processing the mismatched feature (here color), but then spread to all other features of a word, including its semantic properties. To clarify, Houton and Tipper use the term "features" to refer to any aspect of an object of attention. In the case of words these features would include, at least, spatial position, physical feature, phonological, morphological, and semantic properties. In the Deacon et al. model, features is limited strictly to semantic level properties.

This mismatch proposal is compatible with the Näätanen (1985) notion of an ERP processing negativity (PN) associated with "a cerebral matching process between the sensory input and the attentional trace" (Houghton & Tipper, 1994). However, Näätanen attributed the PN to the operation of additional mechanisms in the ongoing processing of the relevant stimulus. In the current study, the enhancement of the N400 priming effect was at least in part due to a negative shift for the attended, unprimed S2 stimuli compared with their unattended counterparts. This attentional shift, while present in the LVF/RH, is clearly greater in the RVF/LH. Thus it is possible that a processing negativity that was initiated early on by the mismatch between stimulus color reflects the inhibition of processes in the task-irrelevant stimulus, such as access to consciousness; a proposal that is in line with the theory of Houghton and Tipper (1994).

Another theory that could help explain the results seen in this study is that of Dagenbach and Carr (1994). The attentional center-surround theory draws on the work of Hubel & Weisel (1962) on the structure and function of visual interneurons. In summary, it is established that the action of one visual interneuron inhibits that of its neighbors that fall along a sort of inhibitory border (surround). At the cytoarchetectural level, this border seems to be comprised of microcolumns of like-functioning neurons. These functional groups are structured to amplify the summed activity of their own group and dampen the activity of neighboring groups. Those neurons falling within the center of the structural group and the edge of its surround may not be inhibited, or even mildly facilitated, while those neurons slightly farther away, but falling on the border of this surround, may be dampened. Neurons beyond the center-surround field should not be directly effected, but may be indirectly effected by the action of a mutually connected interneuron.

Dagenbach, Carr, & Wilhelmson (1990) first proposed a CSM as a possible mechanism to explain unexpected results in a masked behavioral semantic priming paradigm. Subjects were required to make lexical decisions to targets following masked primes, and their performance varied as a function of the threshold setting task used. In the key condition, participants performed a semantic similarity judgement task in the threshold setting phase, which lead to related words being responded to less quickly than words from an unrelated baseline condition. This finding lead Carr & Dagenbach (1990) to replicate and extend these findings using both semantic and repetition priming as part of the same task. In the first phase of this study, subjects made either detection, or semantic similarity judgements under the assumption that the later would encourage subjects to continue to use primarily semantic information to complete the lexical decision task in phase two. The prediction was that when subjects encountered a masked prime it would produce relatively little activation, and they would subsequently focus their attention on the prime. This attentional allocation would take the form of increased activation for the weak prime, in conjunction with a decrement in activation for associated words (CSM). Results indicated that subjects in the semantic decision condition showed facilitation for responses to repeats, and inhibition for semantic associates.

In an extension of this work, Barnhardt, Glisky, Polster and Elam (1996) presented subjects with the task of attempting to learn the meanings of 52 highly uncommon words, with the knowledge that their memory would be tested after a short delay. These words and their definitions were presented for only 7 seconds, in succession, with the effect that they were difficult to remember. The experimenters trained the subjects to the point at which they could recall approximately 50% of the definitions when presented with the rare word, in order to establish relatively weakly represented concepts in semantic memory.

When targets were weakly associatively related to the primes lexical decisions were speeded only for correctly recalled words. But, following synonyms of the rare word responses were speeded regardless of their being remembered or not remembered. They interpret this finding to support a model in which very closely related words, such as synonyms (Barnhart, Glisky, Polster, & Elam, 1996), and repeats (Carr & Dagenbach, 1990) have a facilitatory relationship, due to their proximity in semantic space. On the other hand, those words which are weakly associated are inhibited so as to better differentiate them from the weakly associated concept. Unrelated words would fall beyond the edge of this "center-surround mechanism" (CSM), and hence would be unaffected.

A recent electrophysiological study provides some evidence of the operation of a center-surround mechanism in the LH (Deacon & Shelley-Tremblay, in preparation). As in Barnhart et al., the subjects were taught the definitions of novel words in a learning phase, and then those words served as primes in a test phase. However, Deacon and Shelley-Tremblay used lateralized presentation of the primes and targets. The primes were followed by either associates or synonyms, with the result that a significant N400 priming effect emerged for the RVF/LH synonym condition, but not for the associate condition. The LVF/RH condition failed to demonstrate significant priming effects for either condition, thus complicating the interpretation of the LH results. However, the fact the prime-target pairs were not constructed specifically to share common semantic features and also failed to show priming was consistent with the Deacon et al. (in press) model. The finding of N400 priming in under conditions that favor attention, and a disruption of that priming in conditions where attention should be acting to inhibit information that could conflict with the purpose of the task in the Deacon and Shelley-Tremblay study as well as the current investigation make the action of such an inhibitory mechanism likely. The possible operation of such a mechanism is consistent with the notion of a LH centered attentional mechanism of the type proposed by Nakagawa (1991, reviewed above).

An alternative to the Deacon et al. model that has received considerable attention is that of Beeman (1998). His hypothesis is that the LH utilizes fine semantic coding while the RH uses course semantic coding. By "fine" and "course" Beeman means that the LH activates relatively few possible meanings and key semantic features to a large extent, while the RH activates a larger number of possible semantic interpretations and accompanying semantic features, and maintains their activation for a longer period of time. It is possible that the results of Deacon and Shelley-Tremblay (in preparation) could be accommodated in the Beeman model by arguing that the synonyms and close associates were appropriate stimuli for the RVF/LH because of their high degree of relatedness to the rare prime. Using the same logic, one could argue that the organization of the LVF/RH was not conducive to processing such closely related stimuli, and so this lead to the finding of no priming within the RH only. However, to this model one would have to add a mechanism, such as the center-surround proposed by Dagenbach and Carr, to explain the finding of no priming for associates in the RVF/LH. A more parsimonious explanation for both the Deacon et al. (in preparation) results and those of the present study is that the RH is composed of a featural network that a) was not configured to process the stimuli in the former study because of the lack of shared features between primes and targets, and b) was not subject to attentional modulation in later study because the attentional control exerted acted to modulate spreading activation which was only in operation in the LH.

One of many unanswered questions is whether the attentional effects observed in the RVF/LH condition of the present study were the result of attentional resources that only exist within the LH, or whether they were the result of the action of more central attentional resources that could only effect the LH (and not the RH) in this particular paradigm. Dozens of studies, and several attentional models postulate an important role for the RH in attentional processing (see Heilman et al., 1983; Mesulam, 1987). These studies are largely based on neuropsychological evidence derived from studies of persons with visual neglect. As such these models deal mostly with the orienting of visual spatial attention and the subsequent regulation of eye movements (see also Posner and Petersen, 1990). For this reason, it is tempting to think such models relevant only the initial stages of the current task when subjects must maintain eye fixation, but allocate enough attention to the periphery to complete semantic processing of attended stimuli. However, the work of Bisiach and colleagues (Bisiach, Luzzatti &, Perani., 1979; Basso, Bisiach, &

Luzzatti, 1980) suggests that those with visuo-spatial neglect also show deficits in the orientation of attention to internal representations.

In one study by Bisiach, Capitani, Luzzatti, & Perani (1981), the neglect patients were asked to take a mental 'walk" around a well known public square in their home town. When they were asked to imagine themselves at one end of the square, and then list all the buildings that they "saw" in their mind's eye as they walked through the square, they listed only structures on their right side, as they would have if they were actively perceiving instead of remembering. To rule out the possibility that their injury had resulted in amnesia for the items on the left, the patients repeated the mental walk starting from the opposite side of the square, but this time they reported the previously unreported buildings now on their right side, and failed to report most buildings that had been previously listed. In combination, these findings suggest that the source of the retrieval difficulty was attentional orientation to the representations of specific objects, and that this was the result of injuries to the right parietal lobe. It is likely then that the RH plays some role in the attentional processing of mental representations. However, in this study, the subjects never lost access to the semantic information about what a building was, per se, but simply the presence of specific structures, perhaps implying more of a role for the RH in episodic retrieval.

One theory that explored the question of central attentional control versus hemispheric independence of control was proposed as the result of a series of studies by Hardyk (reviewed in Hardyk, 1991). Hardyk noted that Bryden (1978) commented that "lateralization researchers tended to place too much reliance on interpretations of observed cerebral lateralization differences as indicative of structural differences in the brain" (Hardyk's {1991} paraphrase). In line with the attentional bias theories of Kinsbourne (Kinsbourne, 1970; 1973; 1975), Hardyk argued that one should only postulate structural differences when equally plausible alternatives, like attentional bias, had been ruled out. To address this contention, Hardyk performed a number of lexical decision experiments using lateralized presentation of word and non-word stimuli in conjunction with special hardware to ensure that stimuli were not presented until the eyes were centrally fixated. His studies pointed to the conclusion that the RVF/LH advantage found in lexical decision tasks was modifiable by instruction-induced changes in allocation of visual attention when it came to RT performance, but not accuracy. Furthermore, he showed that biasing to the LVF attention had the effect of equalizing LVF and RVF performance, but that the converse was not true. In these studies, the equalization was the result of equal parts decrement of the LH RT performance and increment of the RH RT performance, indicating the operation of a central resource store that was normally biased towards RVF stimuli.

However, after an additional series of studies, Hardyk began to endorse a proposal by Friedman and Polson (1981) that the RH and LH are parallel, non-interacting resource systems. In this framework, each hemisphere can do any task, but "differences in hemispheric performance reflect differences in resources available between the hemispheres (Hardyk, 1991)." One possible explanation of the results of the two new studies presented in this dissertation is that the LH is responsible for all of the processing observed in both VF conditions, but that the RH waveforms represented the effects of degradation due to callossal transfer. Hardyk proposed a method for testing such a possibility. He reasoned that if the LH and RH both process the information received initially by that hemisphere, and then only share the results of the processing (in the case of lexical decision, 'word vs non-word') then doubling the workload in the task should produce a relative decrease in performance overall, but not in relative performance. If on the other hand, all processing was carried out in the LH, and then transferred, then doubling workload should cause only RVF/LH performance to drop dramatically. It would be an interesting project for the future to manipulate the task demands of the current ERP paradigm and determine the effects on N400 priming. Based on the newly acquired results, it seems unlikely that all of the processing was carried out in the LH and then transferred to the RH because one would expect a decrease in the priming effect overall with transfer, and it is very difficult to conceive of the LH processing information that came across the corpus callosum, then suppressing the results of the processing for itself, but passing the results back to the RH to be expressed. While possible, this explanation is far from parsimonious.

The conclusion of the Hardyk studies was that the RH and LH had two separate lexicons with two separate but unequal stores of processing resources. While his studies pointed to a relative lack of hemispheric interaction, this is still largely an empirical question. Diana Deacon has proposed a follow up study to the present two experiments in which the prime (S1) is presented to the LVF and the target (S2) to the RVF, or the opposite, with the expressed purpose of testing whether attentionally based inhibition originating in and RVF/LH prime can serve to inhibit the processing of an LVF/RH target.

One model that has been influential in setting the stage for general theories of hemispheric differences is that of Goldberg & Costa (1981). Their theory characterized the RH as specialized for the processing of novel stimuli, and the LH as best at the storage and processing of compact codes. In addition, the divided in the hemispheres along a continuum of intermodal (RH) through unimodal (LH) processing styles. The upshot of their theory is that the RH is specialized for the initial stages of knowledge acquisition, while the LH processes well-learned material rapidly and efficiently. They cited as evidence a series of neuroanatomical studies about hemispheric differences in size and morphology of structures, such as the well-established temporal plane asymmetry (Geschwind & Levitsky, 1968).

Furthermore, they cite evidence that the RH is characterized by a concentration of associative cortex, relative to sensory and motor cortex, while the LH shows the opposite pattern. These facts, in conjunction with the findings of relatively short distance, intra-regional cortico-cortical connections in the LH and longer, inter-regional connections in the RH lead them to the hypothesis that the RH has an overall increased capacity for complex cognitive functions. They noted that patients with RH lesions performed significantly worse on complex cross modal integration tasks than LH lesioned patients, with the converse pattern observed for unimodal processing tasks.

While their theory is interesting, it has trouble accounting for the results of the present study. The finding of robust N400 priming in the right hemisphere (attended condition) makes a simple explanation of Goldberg and Costa's theory difficult because the priming effect is based entirely upon the processing of common, well-learned nouns. This theory may have particular difficulty explaining the results of Deacon and Shelley-Tremblay (in preparation) described above. In this study, the hypothesis that the right hemisphere should subserve new learning was directly tested, and the lack of any significant priming in the LVF/RH condition is directly contradictory to the Goldberg and Costa theory. One might only salvage the Goldberg and Costa theory if one takes the Deacon et al. (2003) position that the RH was simply not sensitive to the relationships between the particular stimuli employed in that study (no shared features), but might have shown priming for new words with strong featural overlap.

Other important models of attention, such as the Mirsky (1996; Tatman, Fantie, & Mirsky, 1995) are primarily general formulations of the overall structure and functions of the attention system. This model specified 5 unique elements that they felt were essential for capturing the range of attentional phenomena observed in the clinical and cognitive literature. They were set out as a "restricted taxonomy of attentional functions," and included: scan/focus/speed, shift/be flexible, arouse/exert, encode/retain, and stabilize/steady. As with all cognitive models the factors are under continual revision. What is clear is most real-world tasks involve the majority of these functions, and in the case of the present study, many were engaged at the same time. The contribution of this study to such general models may be that it helps to remind the authors of the necessity of specifying the possibility of, and formulating the parameters under which the different attentional subsystems interact over the course of a common task such as reading. As was indicated in the introduction, too often models of attention are not integrated effectively into other general models of cognitive function, and vice-versa.

SAEs

One finding to be explained was the presence of SNs in the LVF/RH in Experiment 1 without FSPs, while in Experiment 2 significant FSPs emerged without significant SNs. While the tasks were ostensibly the same for subjects performing Experiments 1 and 2, in Experiment 1 their was no need to switch attention within a critical trial. Thus, subjects may have engaged slightly different cognitive strategies that are reflected in the presence of significant, but different SAEs for Experiments 1 and 2.

The finding of N400 priming for the RH in both Experiments 1 and 2 in unattended stimuli suggests that the presence of SAE correlates of color selection are not de facto evidence of early selection. As suggested above, the appearance of an SAE may be an index of a process that serves to designate stimuli as to-be-attended or to-be-ignored, and that "ignore tags" affixed to irrelevant stimuli are treated differently by the LH and the RH semantic systems.

Perhaps the main proponent of the early selection view in recent literature has been the group of Hillyard and Mangun (Heinze, Luck, Mangun, & Hillyard, 1990; Hillyard & Munte, 1984; Luck, Heinze, Mangun, & Hillyard, 1990; Mangun & Hillyard, 1987). They have repeatedly demonstrated that, under certain conditions, visual selective attention can act to prevent or greatly attenuate the occurrence of a late component (the N2) in the unattended stimuli. The N2 has been associated with stimulus classification processes (Ritter, Simson, & Vaughn, 1983). Thus, these authors have argued that evidence of SAEs should signal the operation of early selection, and that irrelevant stimuli receive no processing at the level of classification or beyond.

Drysdale, Finlay, and Fulham (1995) provided some evidence against this simple early selection view. They used simultaneous bilateral presentation to display target, neutral, and non-target single letter stimuli to either the LVF or RVF. The target stimuli were either the letter "A" or "E," and the neutral stimulus was chosen randomly for any neutral trial from a fixed set of 9 consonants. The relevant VF was cued on a trial-by-trial basis. These conditions should have been optimal for eliciting strong early selection (Heinze et al., 1990). The critical test was the presence of a differential ERP response to target and non-target letters in the unattended condition. They found a temporally and occipitally maximum negative peak at 230 msec that was larger for unattended compatible than unattended incompatible targets. If early selection occurred, then Mangun and Hillyard's results would have predicted no N2 activity for the unattended stimuli.

At least two problems exist with the Drysdale et al. study. First, the use of a pre-cuing stimulus that offset immediately before target onset made the interpretation of the ERP up until the 230 ms effect unintemperatable. Thus, although the experimental design should have yielded effective selection, there was no direct ERP evidence of early selection. Second, the latency of the N2 effect was unusually early in comparison with the studies of Hillyard (above), as well as of Ritter et al. (1983). The new experiments presented in this paper provide both ERP evidence of early selection processes, and the finding of an N400 priming effect with standard latency and distribution.

Drysdale et al. concluded that the lack of an N2 in unattended locations in the studies of Hillyard and colleagues may be indicative not of early selection, per se, but of the presence of a stimulus item in the attended location. In other words, all of the studies reported thus far suggest that the components associated with later stages of processing are more likely to occur for irrelevant stimuli if a relevant stimulus is also present in the display. In effect, the N2 would be reflective of a composite response of unattended and attended stimulus classification. In keeping with this, Czigler and Géczy (1996) proposed that both the FSP and the N2 are manifestations of a "task-related, attentive rechecking processes." Using a color-selection paradigm, they found no evidence of an N2 in the unattended stimuli, but simultaneous behavioral evidence of a higher recognition rate for previously presented unattended items. Similarly, Bentin, Kutas, & Hillyard (1995) showed behavioral evidence of higher level processing in their unattended stimuli in the auditory modality.

In a related paradigm, termed the Attentional Blink (AB), Luck, Vogel, & Shapiro (1998) demonstrated an N400 priming effect for target words that were unidentified due to their temporal proximity to a previous target. The AB is thought to occur because conscious access to the output of the word identification system is dependent upon attentional resources which are yet to be disengaged from the first target and reallocated to the second. It has also been demonstrated behaviorally that the semantic properties of the stimulus critically interact with the attentional locus of the AB (Mack et al., in press). In brief, meaningful icons such as a "happy face" show significant resistance to the AB, when compared to spatially equivalent scrambled versions of the same stimuli. These recent studies point to the conclusion that the SAEs associated with early selection do not always signal the cessation of later processes.

The recent, important work on early selection has been summarized by Hillyard, Luck, & Vogel (1999) and synthesized into their sensory gain control mechanism theory of selective attention. This theory specifies the likely neural loci of early selection as residing in visual extra-striate cortex, with mediating inputs from subcortical and frontal sites. The present study suggests that even when this early selection mechanism is operating optimally, it may act to attenuate (Triesman, 1960) more than block (Broadbent, 1958) continued stimulus analysis. The results currently at issue should not be taken as evidence "against" early selection, but should be used in the construction of a theory that effectively accommodates the wide array of evidence that attention can act at almost any point in the processing of visual stimuli, from feature analysis to response execution (see Ilan and Polich, 1999 for a review of attention and response execution). Perhaps the best first step that can be taken in this enterprise is to reaffirm the importance of the PAS in explaining spatial selective attention study results. The present study, like those of Kellenbach and Mitchie (1996) and Otten, Rugg, and Doyle (1993) that show evidence of post-perceptual processing in unattended stimuli using a selection cue that should primarily engage the AAS, with its ventral stream connections. All studies thus far, including the present, are consistent with the theory that late selection is possible when the PAS has not acted to dampen the output of sensory processes to such a degree that word level processing is never initiated.

The uncoupling of the normally unitary reading system into two subsystems by the use of the lateralized presentation technique allows an opportunity to observe the action of the RH that is normally obscured by LH inhibition. The current results are compatible with the suggestion of Nakagwa (1991) that the attentional processing of words is governed by a LH based frontal attention network. Experiment 2 suggests that the presence of an irrelevant prime only may be sufficient to allow the LH frontal attention network to dampen the activation of the target. This study highlights the utility of the ERP technique for gaining insight into processes not open to investigation using behavioral techniques alone. The presence of SAEs in for the LVF/RH condition in both studies may be related to the initiation of a process by which the continued semantic analysis in the RH is blocked from access to LH systems associated with consciously mediated language planning and execution subsystems.

Figures

Figure 1

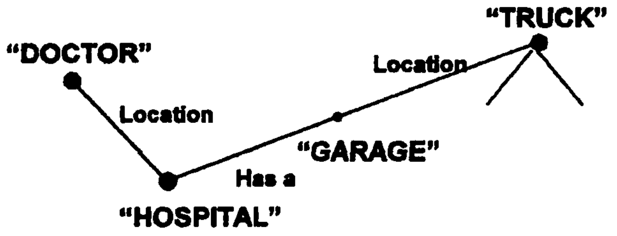

Figure 1: A portion of a local neural network. Words in quotation marks indicate concepts that are represented in nodes (circles). The lines represent associative connections of the sort indicated by the labels, e.g. "DOCTOR" and "HOSPITAL" are related in that a doctor is found at the location, hospital. Strongly associated words are usually depicted as being closer together in the network. Based on Collins & Loftus, 1975).

Figure 2

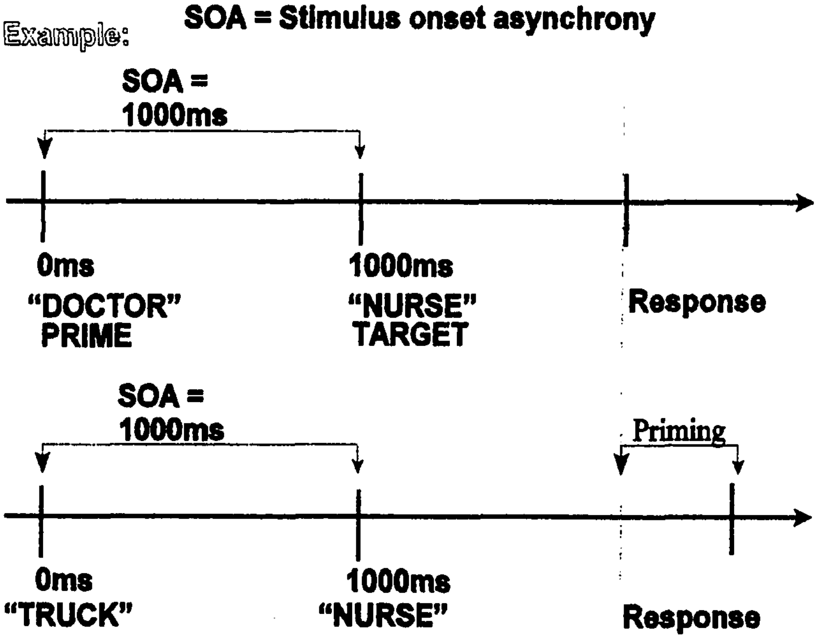

Figure 2: The target word, "NURSE", is preceded by a related prime, "DOCTOR", in the top time line. In the bottom time line, the target word is preceded by an unrelated prime, "TRUCK." The subject is asked to make a speeded response to the target word. A reduction in RT to the target is taken as an indication of the primes facilitative effect on the target.

Figure 3

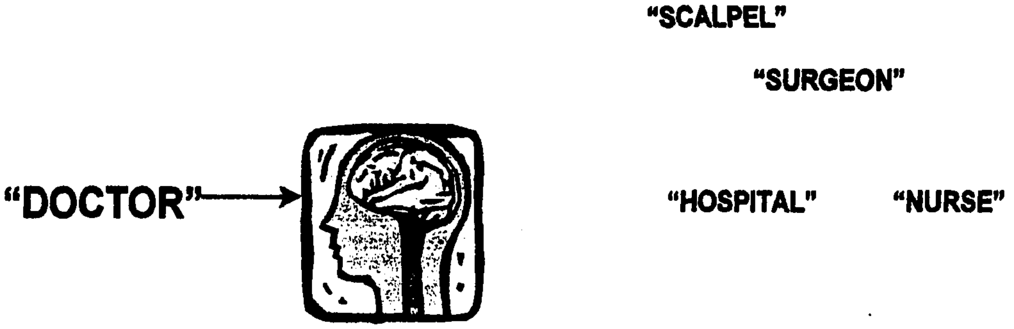

Figure 3: A schematic representation of the semantic expectancy generation process. After viewing "DOCTOR", the subject begins to produce candidate targets based on the expectation of semantic relatedness. If one of the generated possibilities is "NURSE," then response time will be shortened.

Figure 4

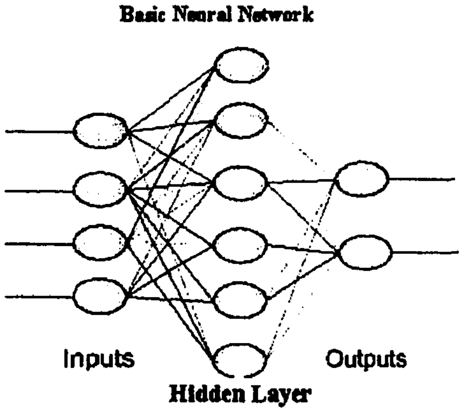

Figure 4: A basic 3 level neural network model with parallel, distributed connections between each of the processing units. Activation levels of each node, on their own, represent no concepts. But, when taken together the unique activity of the output level is suggested to be able to code for any unique concept. Adapted from **www.e-orthopaedics.com/sakura/ images/neural.gif** (Used with permission of the publisher).

Figure 5

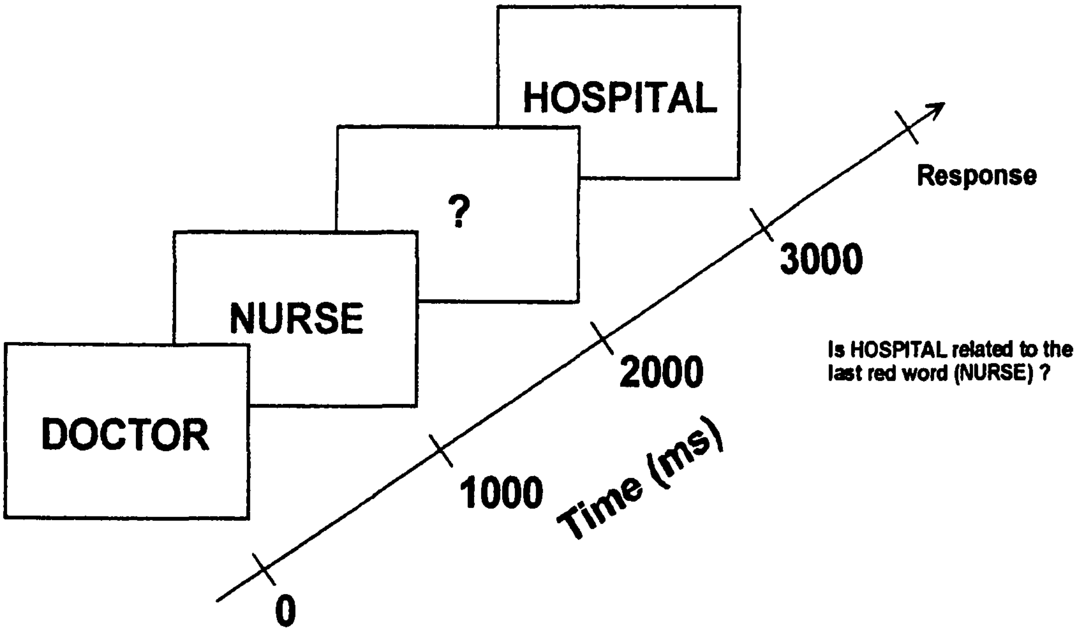

Figure 5: A typical red-relevant trial for Experiment 1.

Figure 6

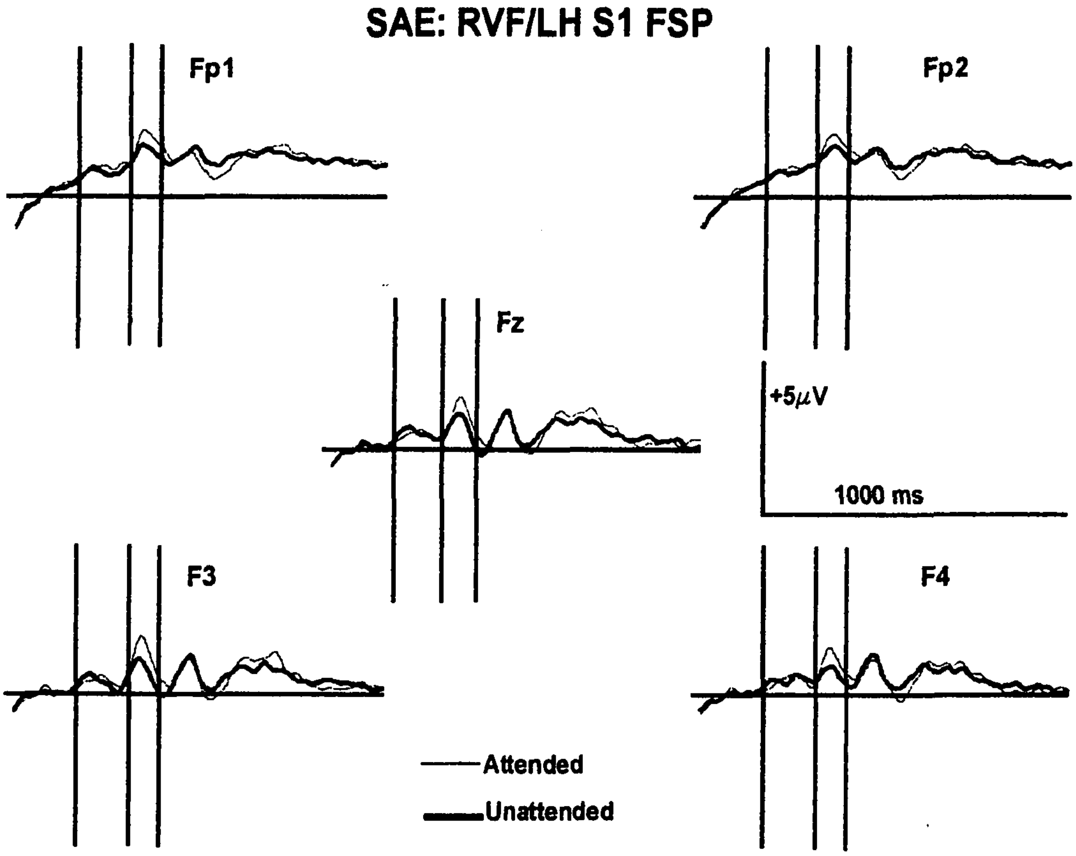

Figure 6: The grand averaged waveforms of the RVF/LH S1 Frontal Selection Positivity (FSPs) for Experiment 1 at the Frontal Sites. For this and all other SAE figures the SAE measurement window is indicated by the vertical bars. Unattended waves are represented as thick black lines, and attended waves are shown as thin grey lines.

Figure 7

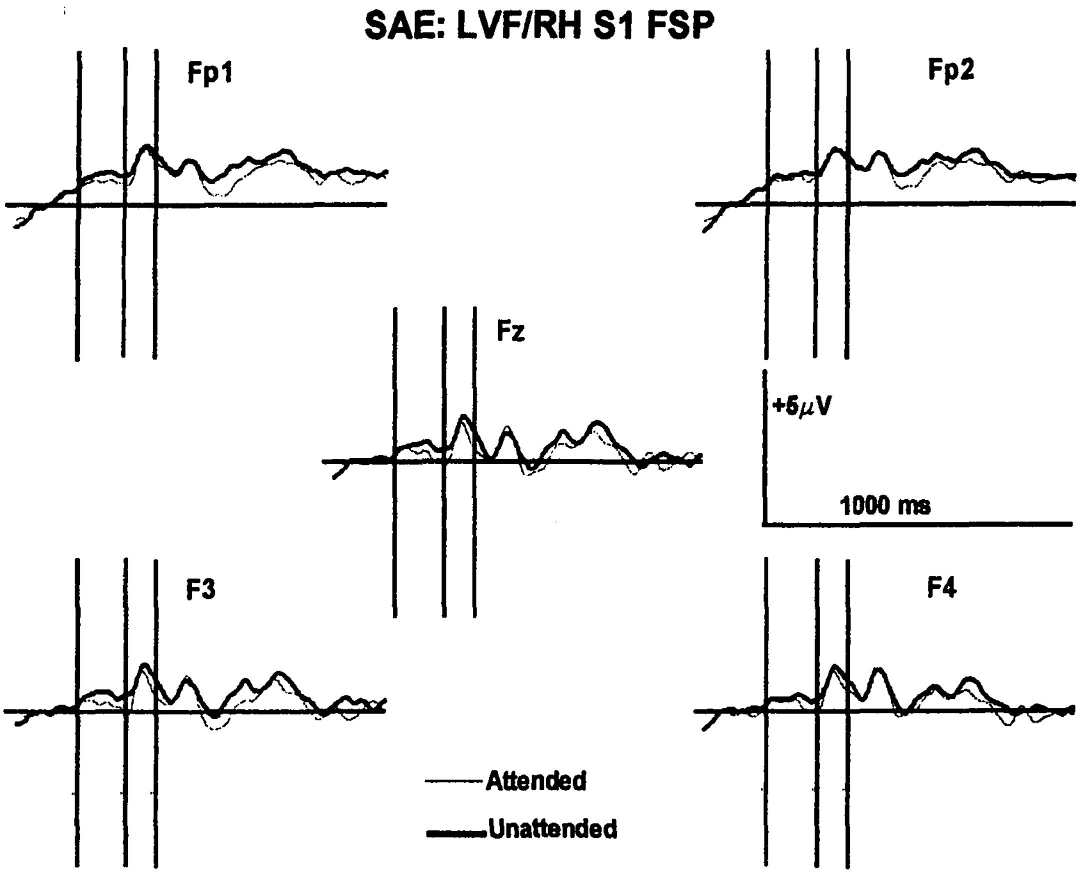

Figure 7: The grand averaged waveforms of the LVF/RH S1 FSP for Experiment 1 at the Frontal Sites. No FSP is visible.

Figure 8

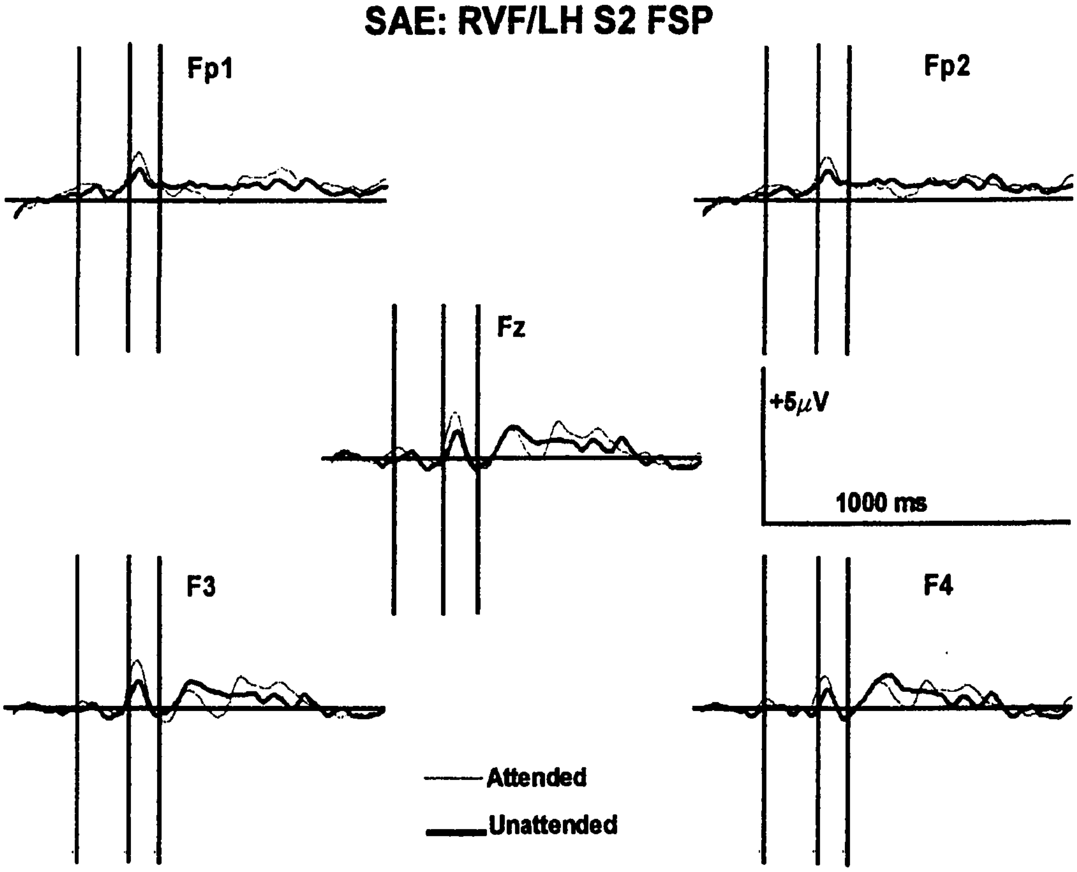

Figure 8: The grand averaged attended and unattended waveforms of the RVF/LH S2 FSP for Experiment 1 at the Frontal sites.

Figure 9

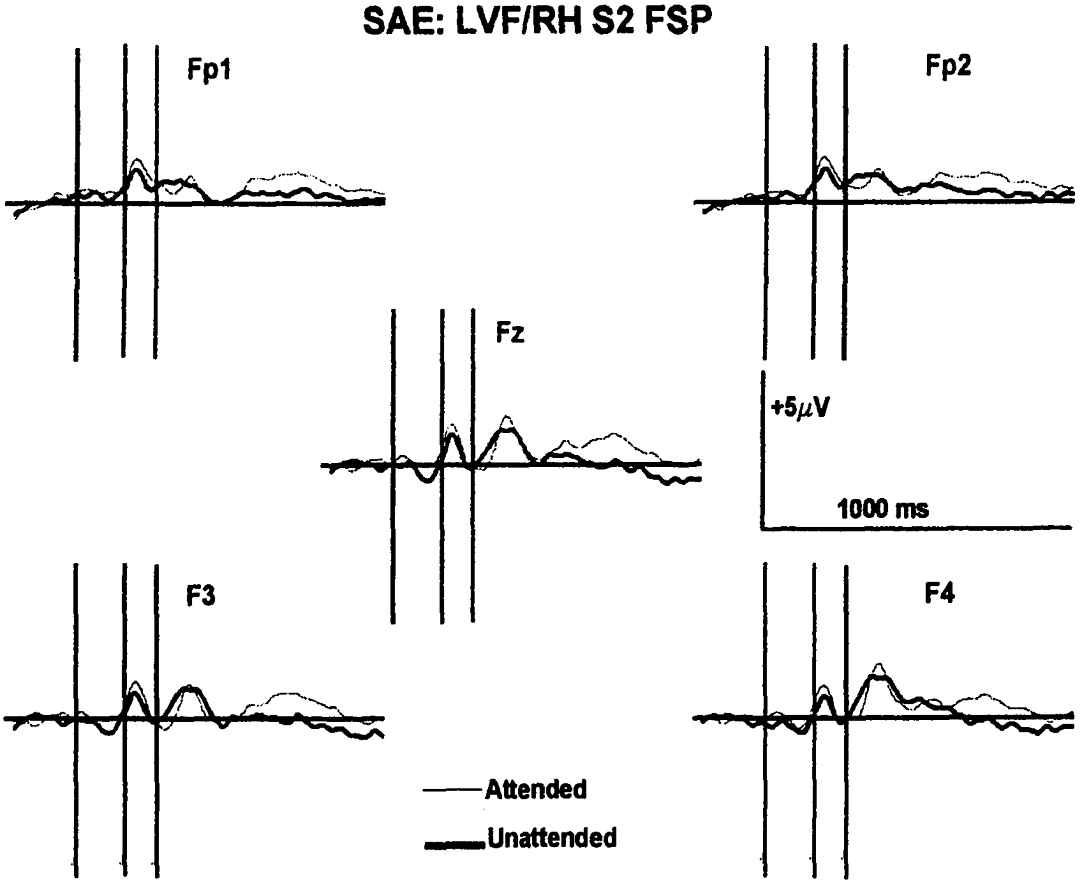

Figure 9: The grand averaged attended and unattended waveforms of the LVF/RH S2 FSP for Experiment 1 at the Frontal sites. The small FSP that is visible was not significant.

Figure 10

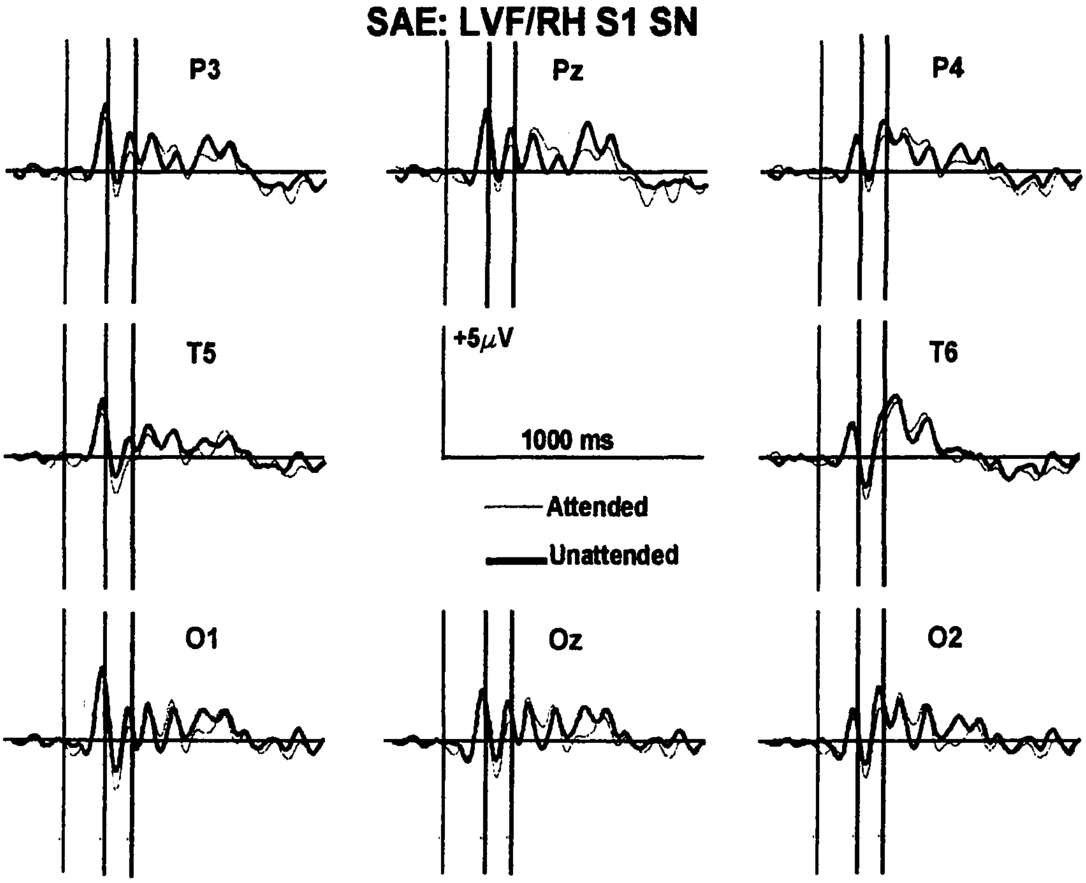

Figure 10: Figure 10 displays the unsubtracted irrelevant and relevant waveforms for the LVF/RH S1 Selection Negativity (SN). Again, unattended waves are represented as thick black lines, and attended waves are shown as thin grey lines.

Figure 11

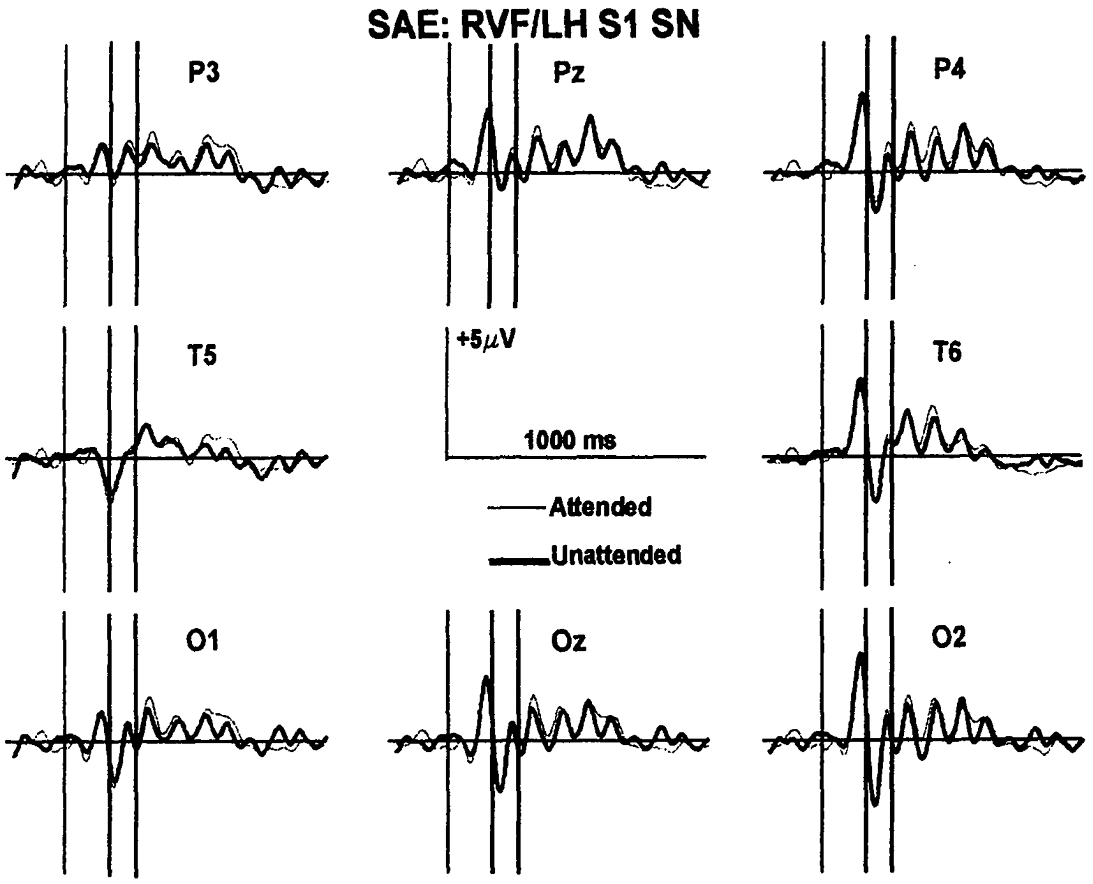

Figure 11: Figure 11 displays the unsubtracted irrelevant and relevant waveforms for the RVF/LH S1 (SN). No SN is apparent at most electrodes.

Figure 12

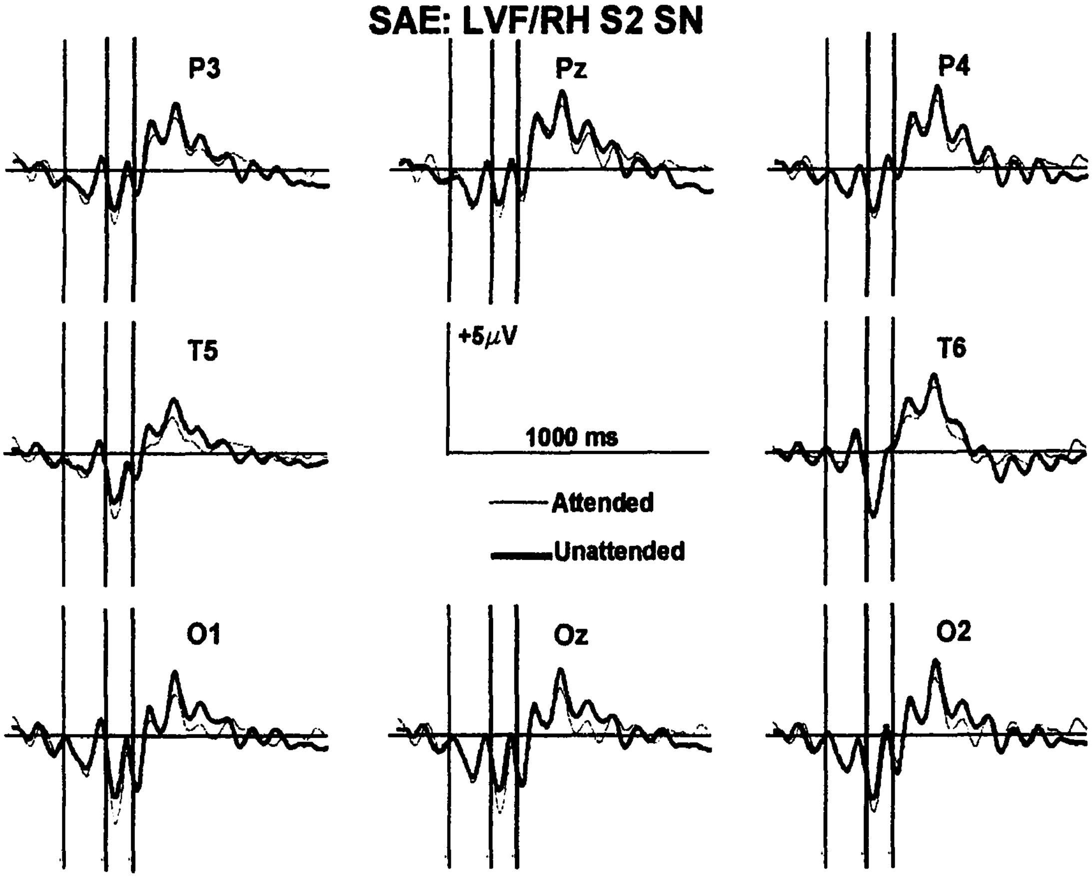

Figure 12: Figure 12 displays the unsubtracted irrelevant and relevant waveforms for the LVF/RH S2 Selection Negativity (SN).

Figure 13

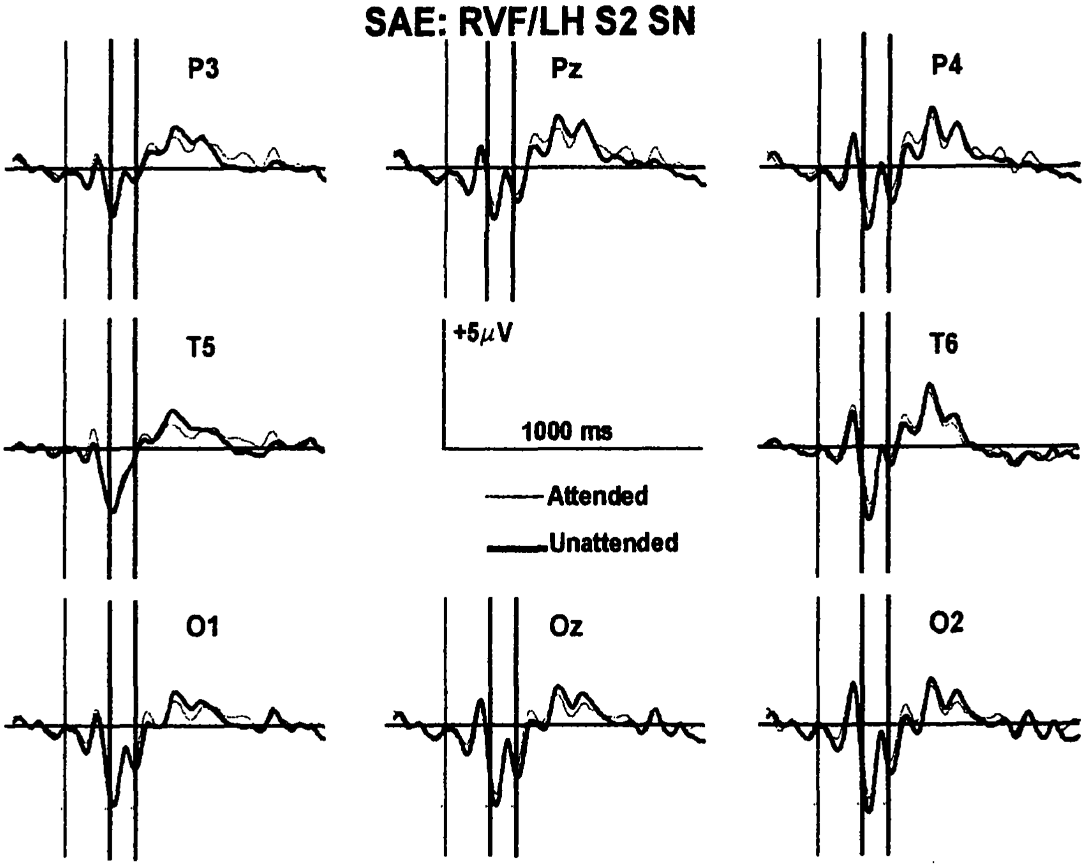

Figure 13: Figure 13 displays the unsubtracted irrelevant and relevant waveforms for the RVF/LH S2 Selection Negativity (SN). No SN can be seen.

Figure 14

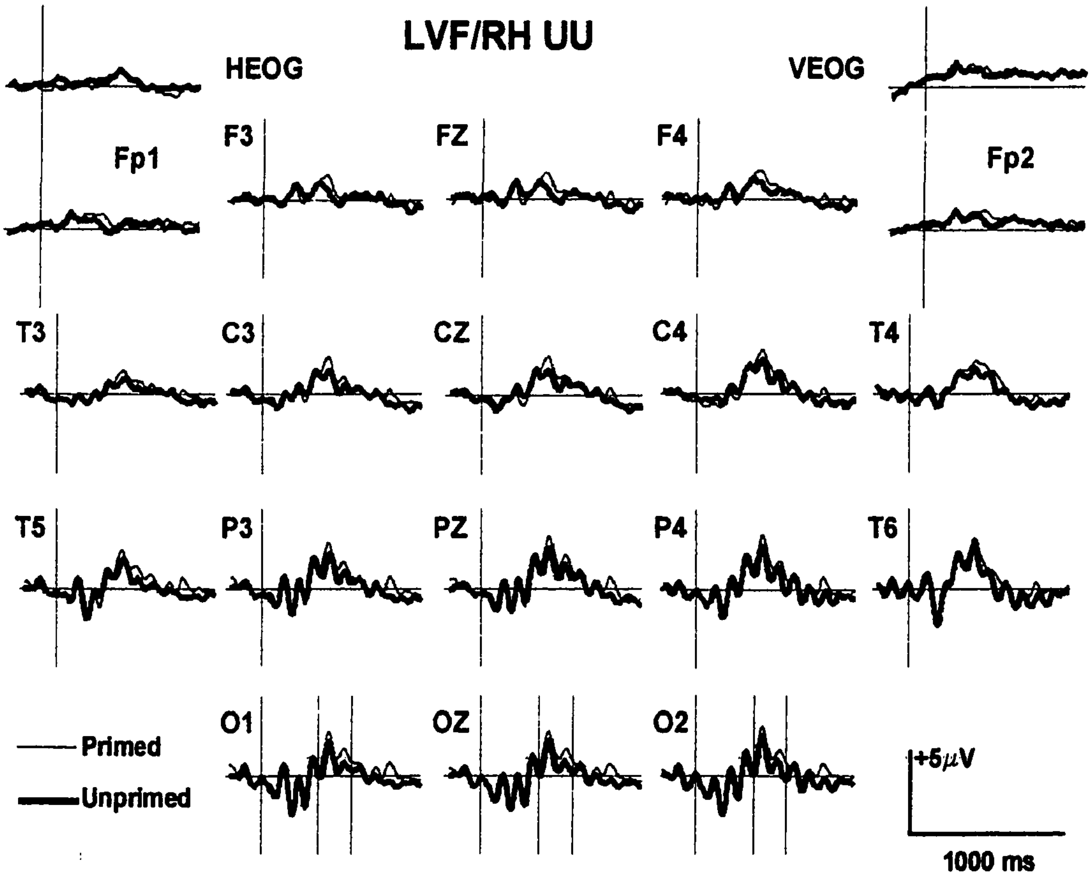

Figure 14: The N400 priming effect for LVF/RH UU condition in Experiment 1. Unprimed waves are represented as thick black lines, and primed waves are shown as thin grey lines.

Figure 15

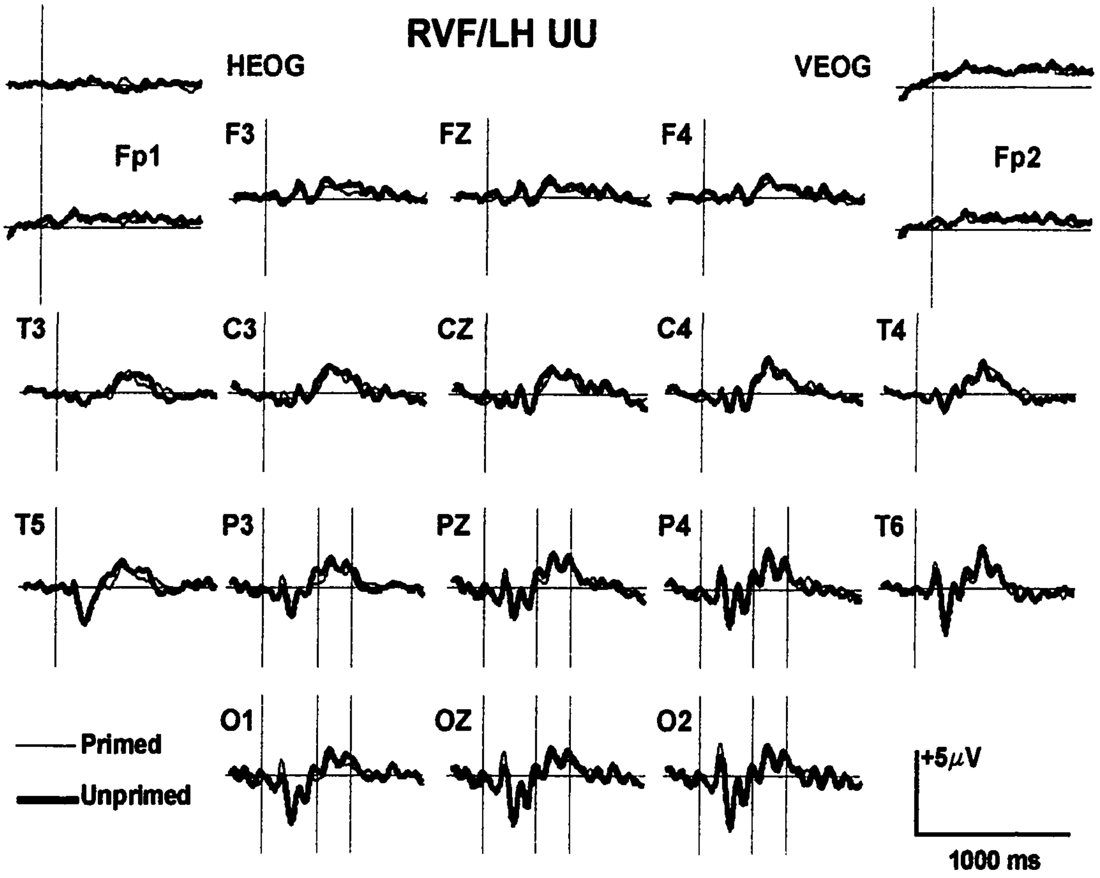

Figure 15: The N400 priming effect for RVF/LH UU condition in Experiment 1. Unprimed waves are represented as thick black lines, and primed waves are shown as thin grey lines.

Figure 16

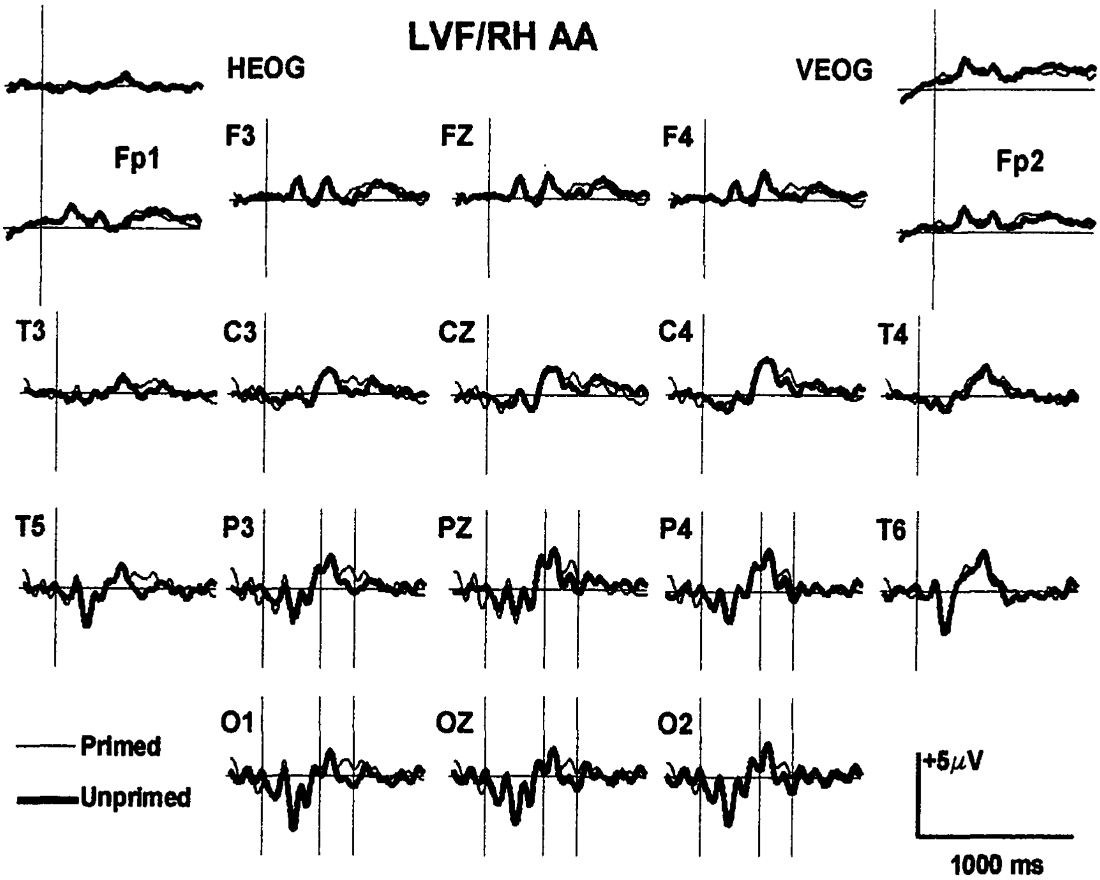

Figure 16: The N400 priming effect for LVF/RH AA condition in Experiment 1. Unprimed waves are represented as thick black lines, and primed waves are shown as thin grey lines.

Figure 17

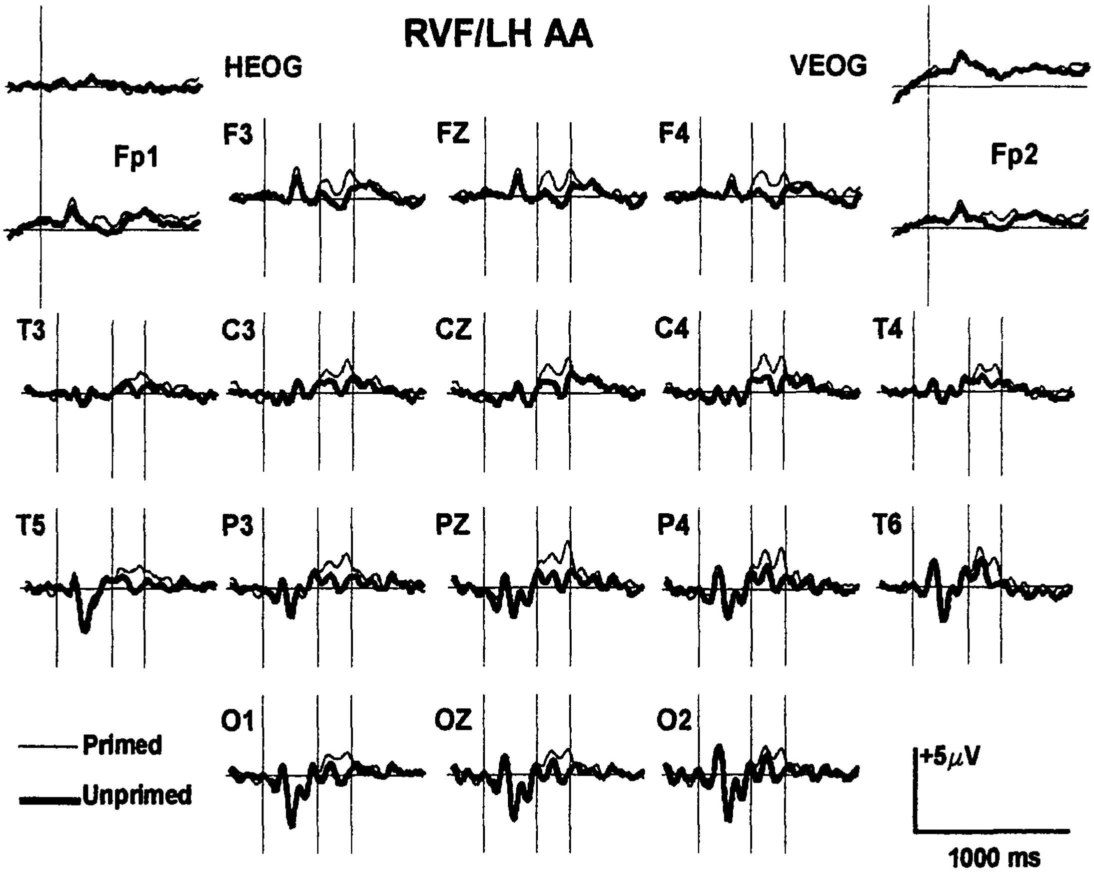

Figure 17: The N400 priming effect for RVF/LH AA condition in Experiment 1. Unprimed waves are represented as thick black lines, and primed waves are shown as thin grey lines.

Figure 18

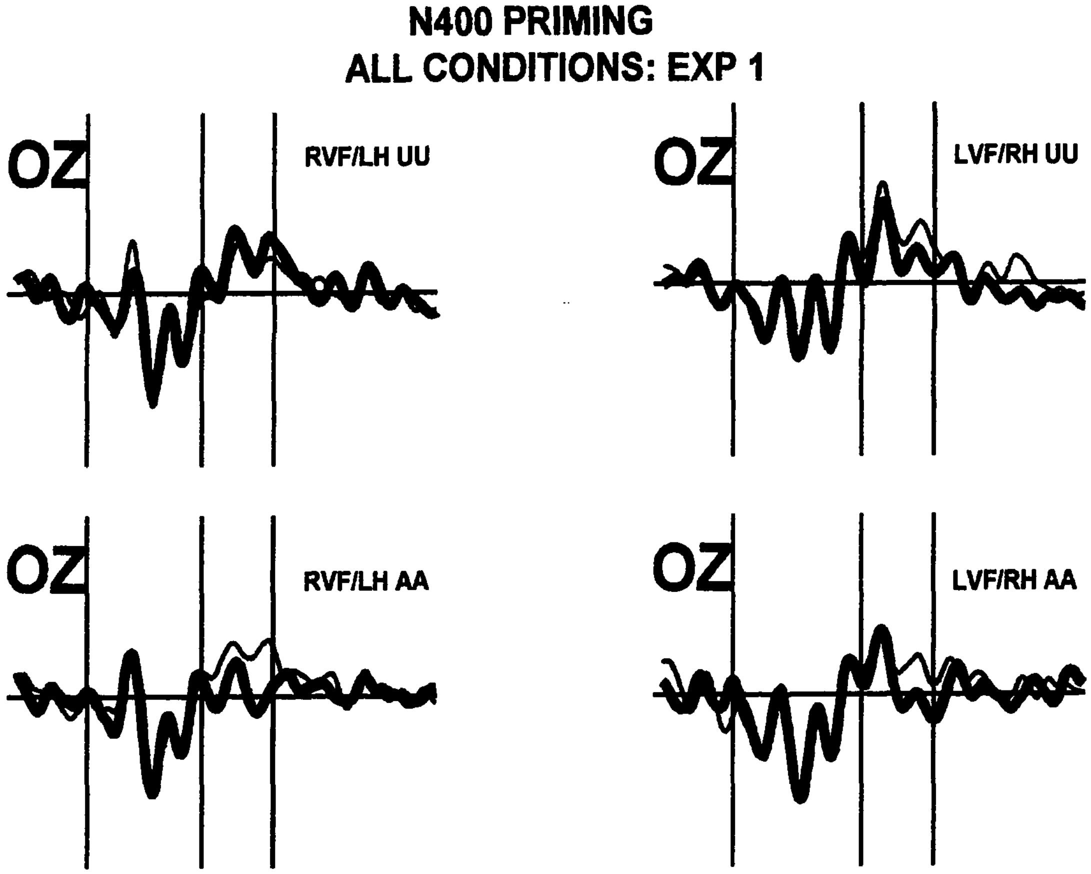

Figure 18: The N400 priming effect in Experiment 1 for all experimental conditions as seen at Oz.

Figure 19

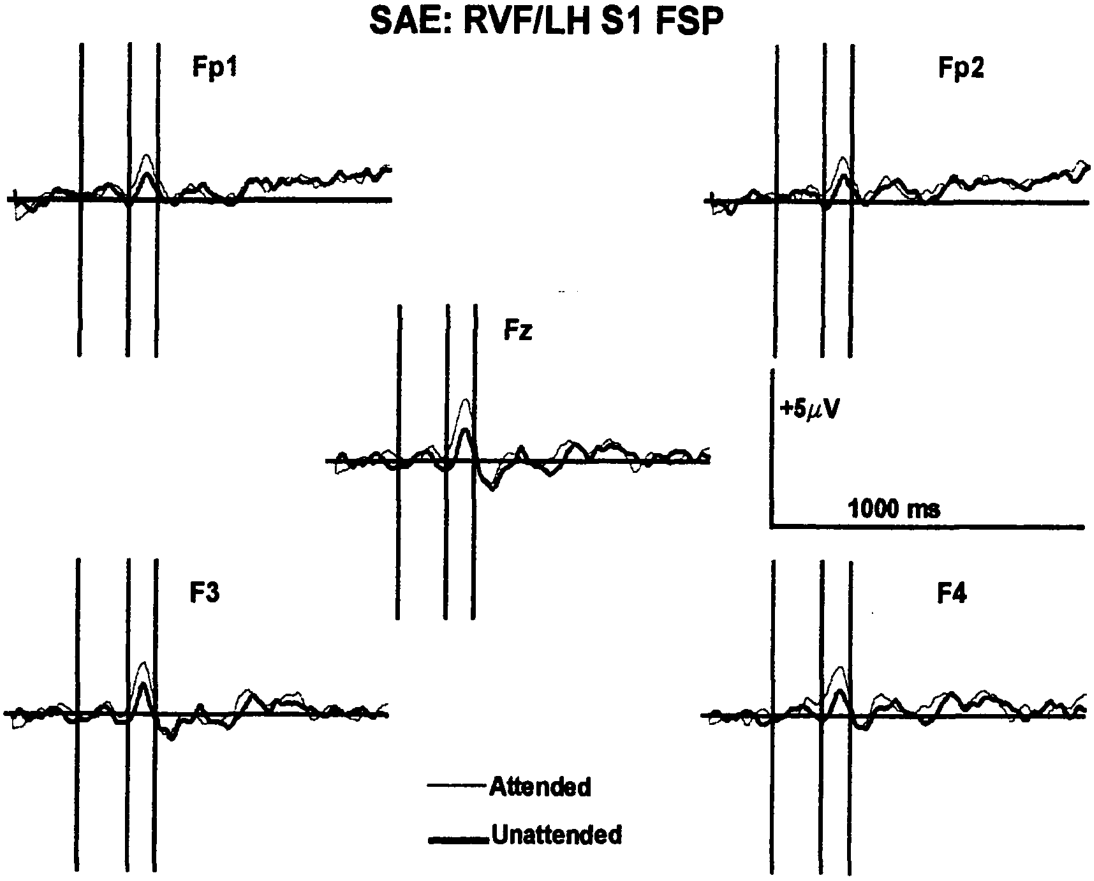

Figure 19: The grand averaged waveforms of the RVF/LH S1 Frontal Selection Positivity (FSPs) for Experiment 2 at the Frontal Sites. Unattended waves are represented as thick black lines, and attended waves are shown as thin grey lines.

Figure 20

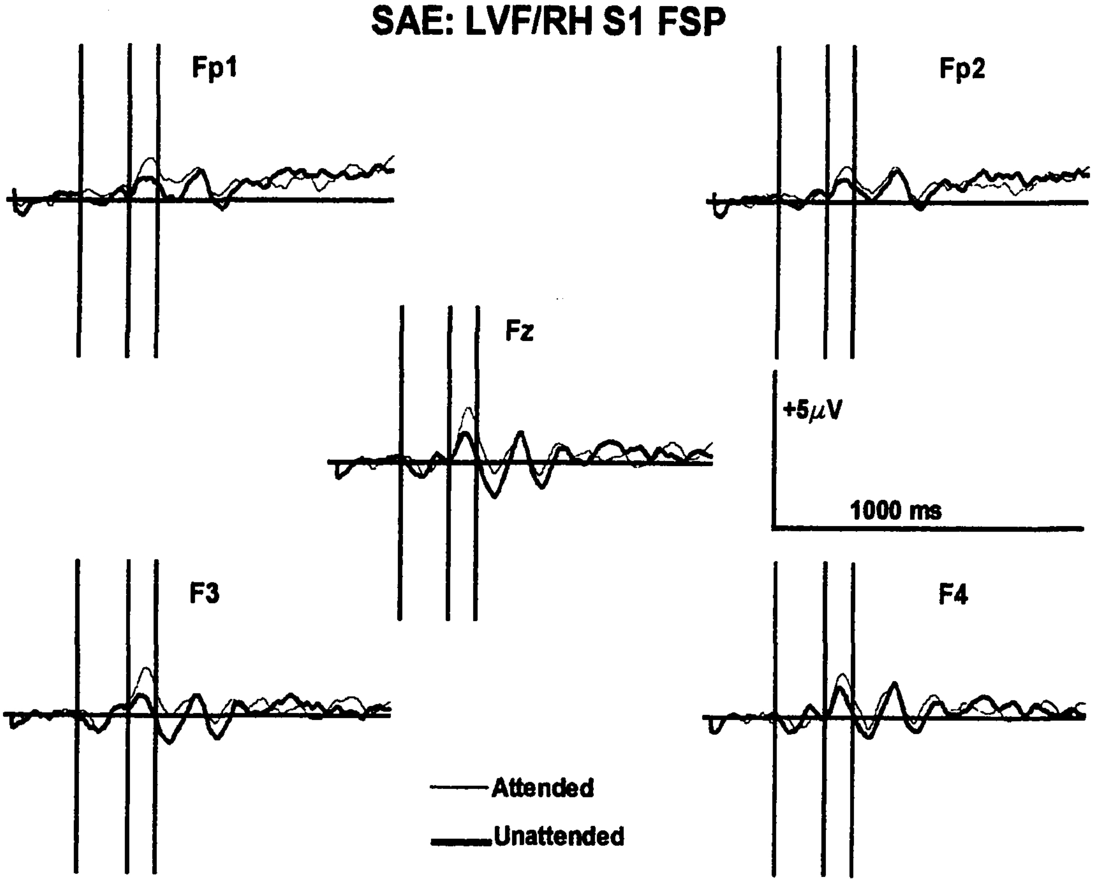

Figure 20: The grand averaged waveforms of the LVF/RH S1 FSPs for Experiment 2 at the Frontal Sites. Unattended waves are represented as thick black lines, and attended waves are shown as thin grey lines.

Figure 21

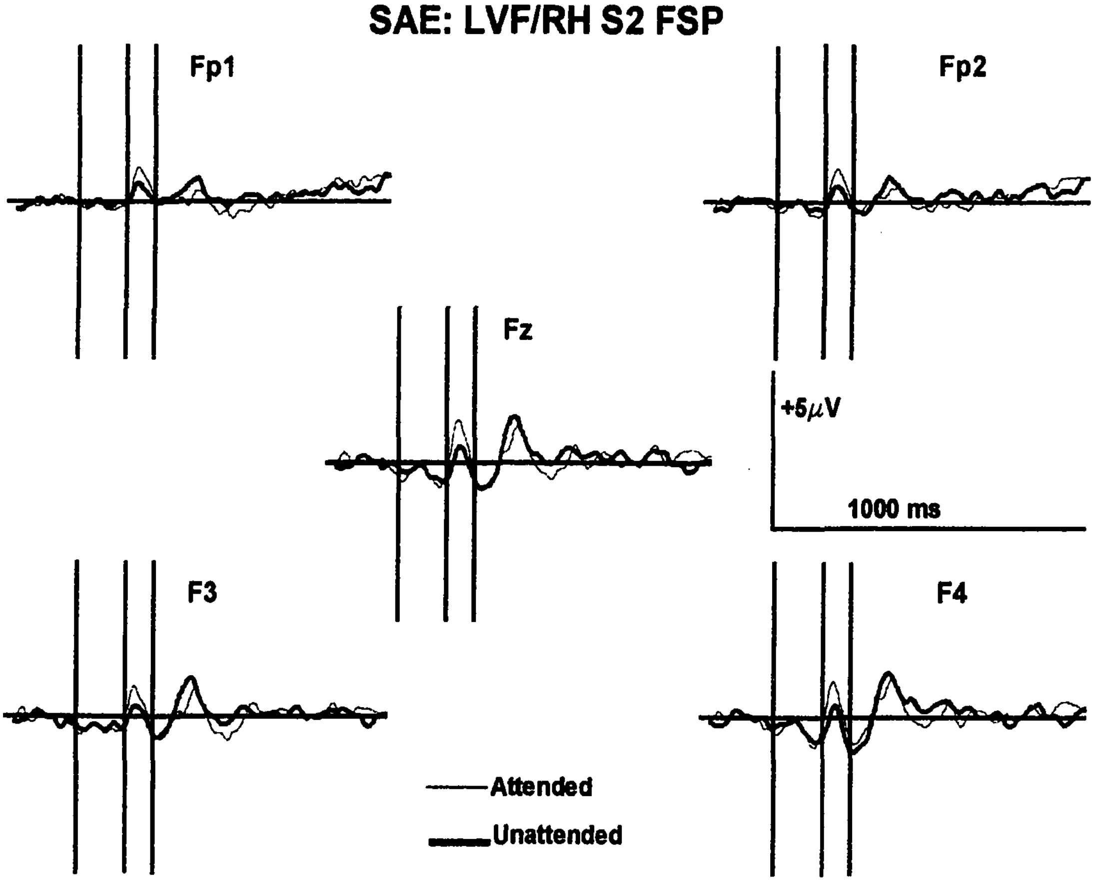

Figure 21: The grand averaged waveforms of the LVF/RH S2 FSPs for Experiment 2 at the Frontal Sites. Unattended waves are represented as thick black lines, and attended waves are shown as thin grey lines.

Figure 22

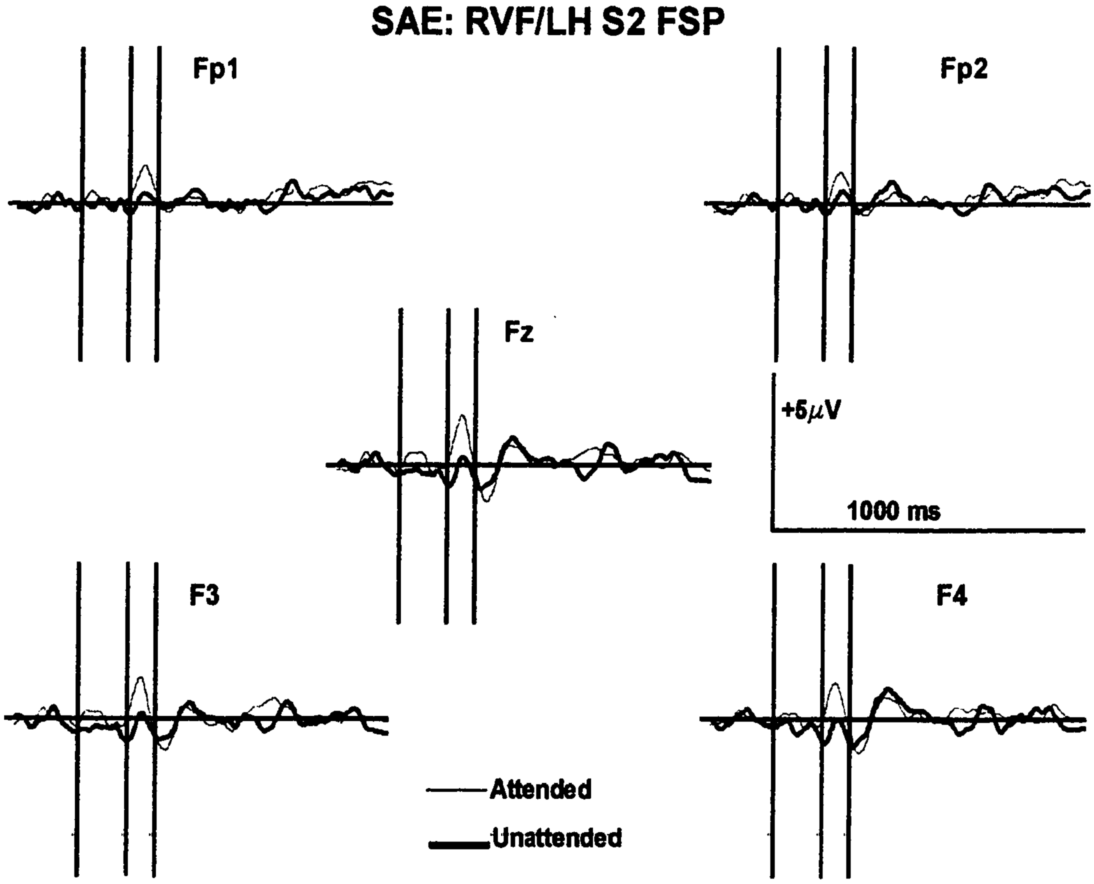

Figure 22: The grand averaged waveforms of the RVF/LH S2 FSPs for Experiment 2 at the Frontal Sites. Unattended waves are represented as thick black lines, and attended waves are shown as thin grey lines.

Figure 23

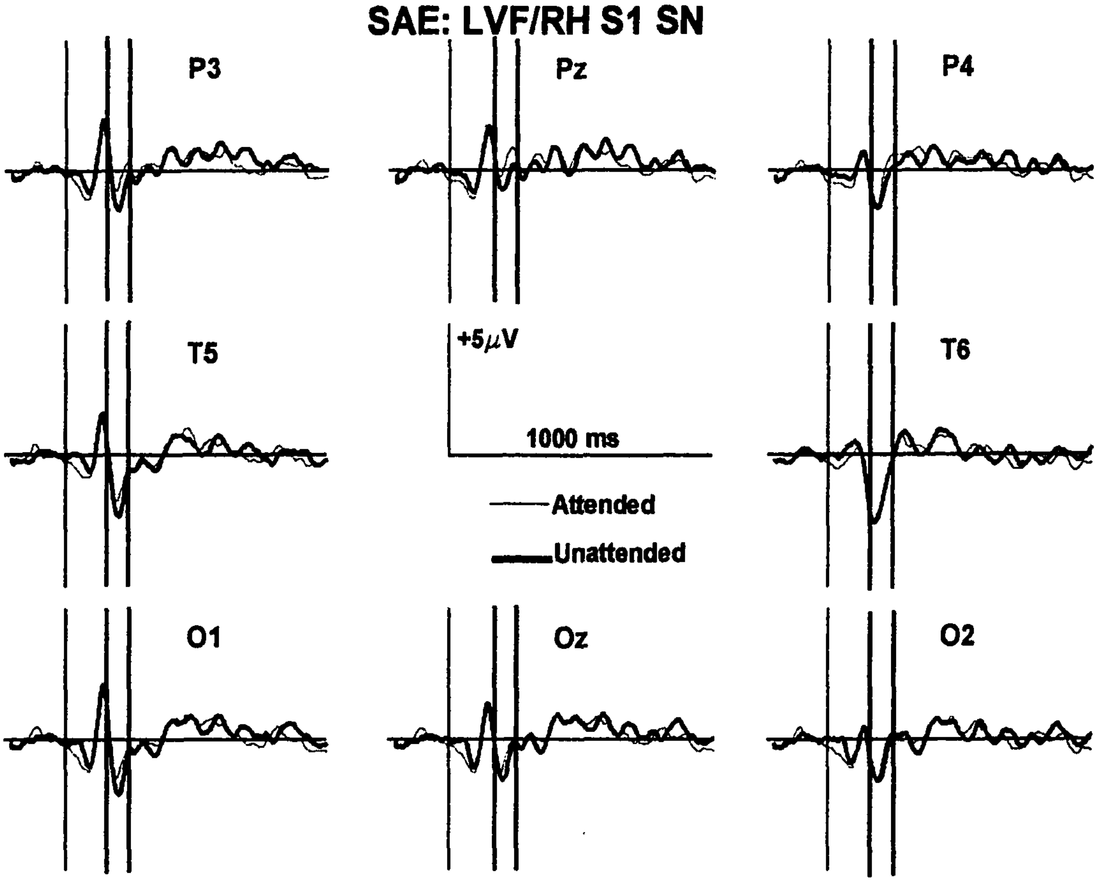

Figure 23: The grand averaged waveforms of the LVF/RH S1 SNs for Experiment 2 at the P3, Pz, P4, T5, T6, O1, Oz, and O2 sites. No SN is present.

Figure 24

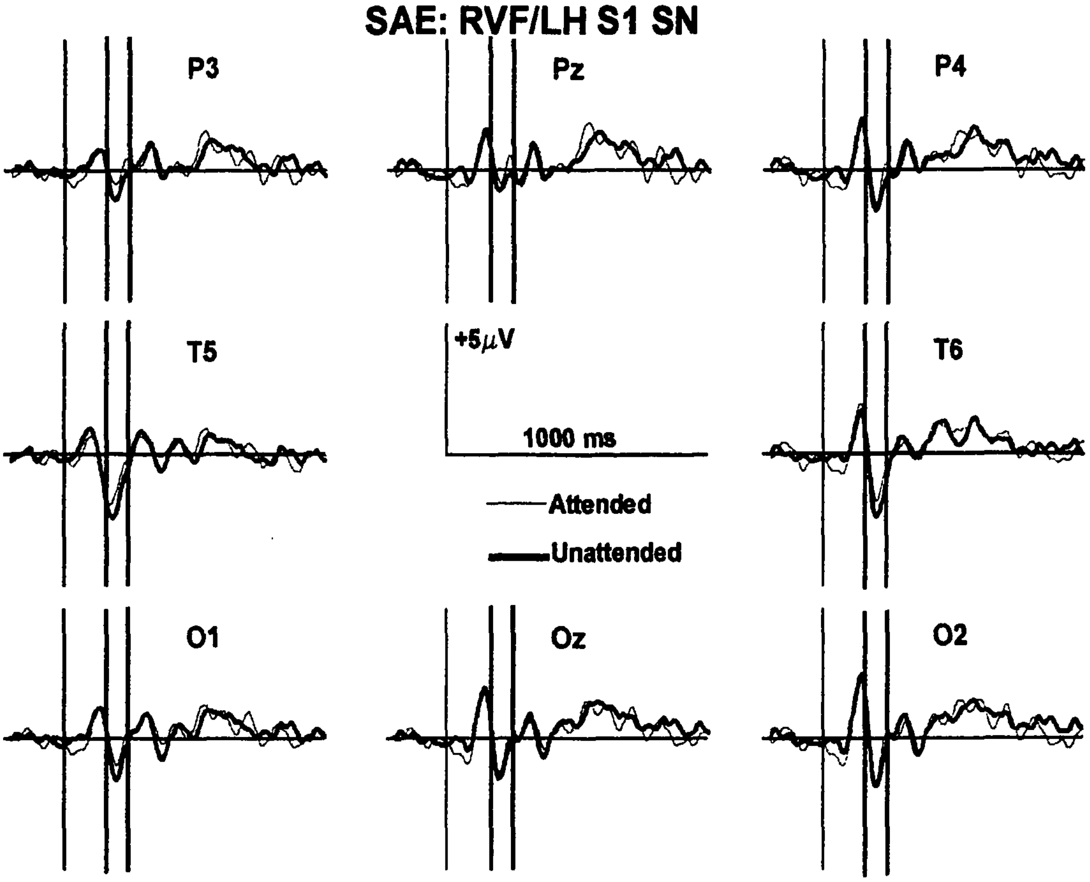

Figure 24: The grand averaged waveforms of the RVF/LH S1 SNs for Experiment 2 at the P3, Pz, P4, T5, T6, O1, Oz, and O2 sites. No SN is present.

Figure 25

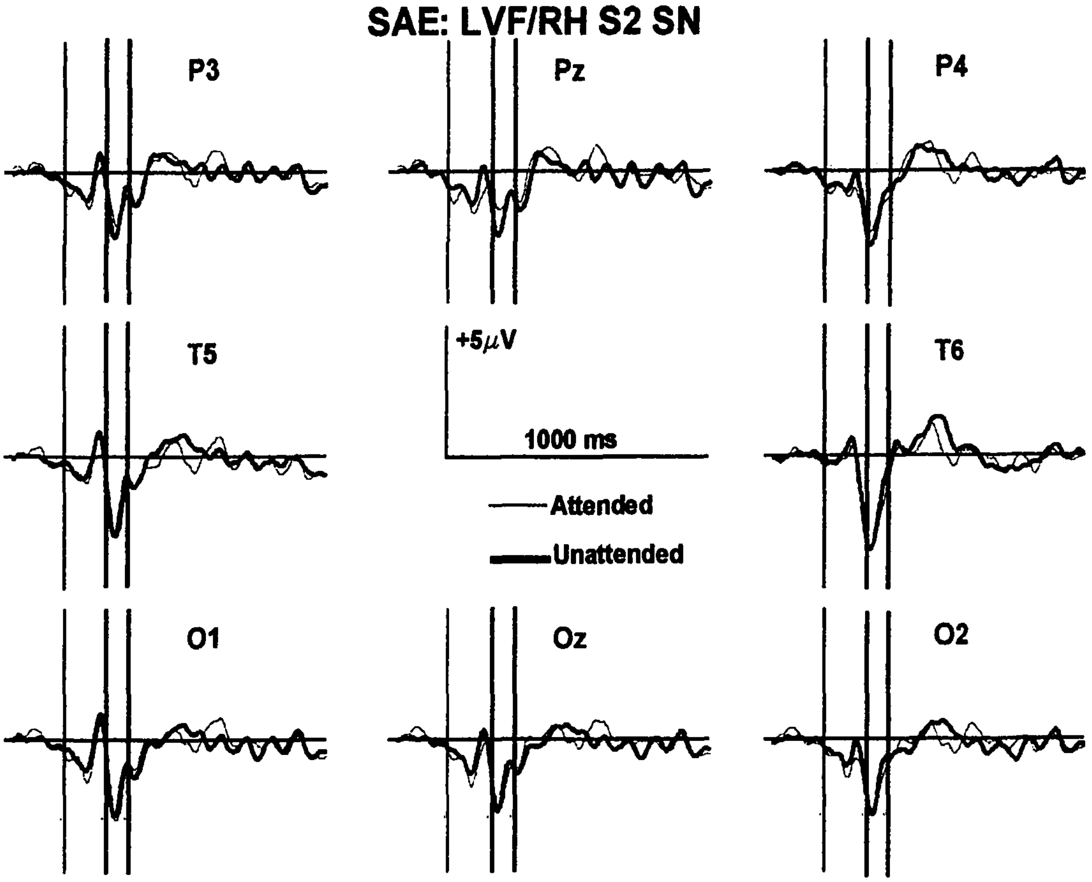

Figure 25: The grand averaged waveforms of the LVF/RH S2 SNs for Experiment 2 at the P3, Pz, P4, T5, T6, O1, Oz, and O2 sites. No SN is present.

Figure 26

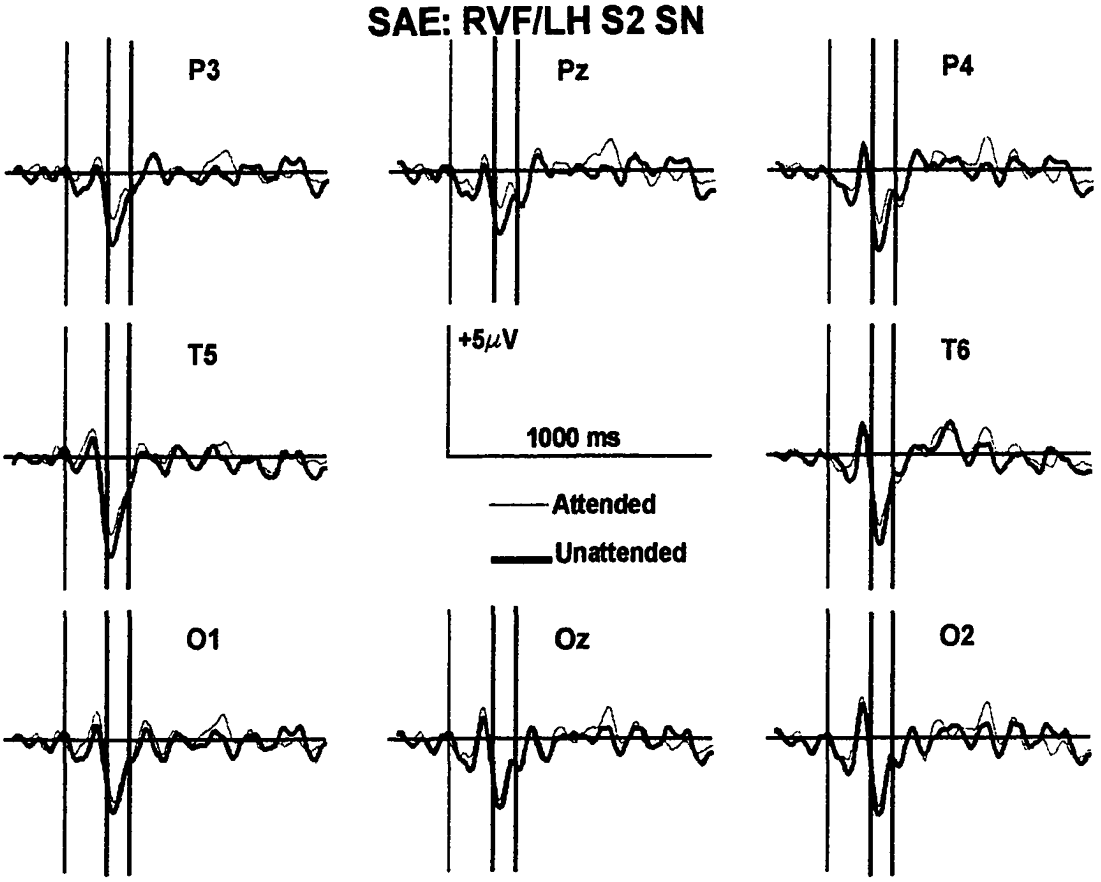

Figure 26: The grand averaged waveforms of the RVF/LH S2 SNs for Experiment 2 at the P3, Pz, P4, T5, T6, O1, Oz, and O2 sites. No SN is present.

Figure 27

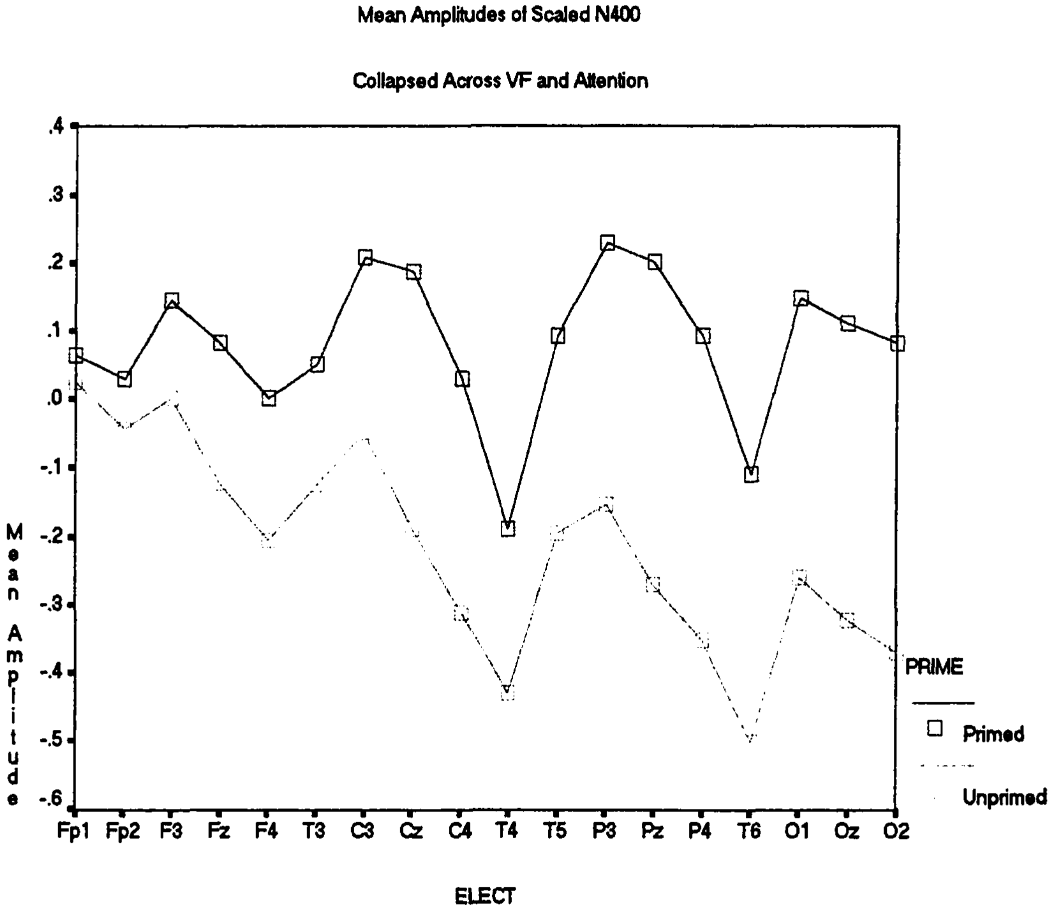

Figure 27: Grand averaged waveforms for Experiment 2 scaled data N400 priming effect collapsed across factors of Visual Field and Attention. Note here how the occipito-parietal maximum for the priming effect persists even after scaling to control for gross amplitude differences between electrodes.

Figure 28

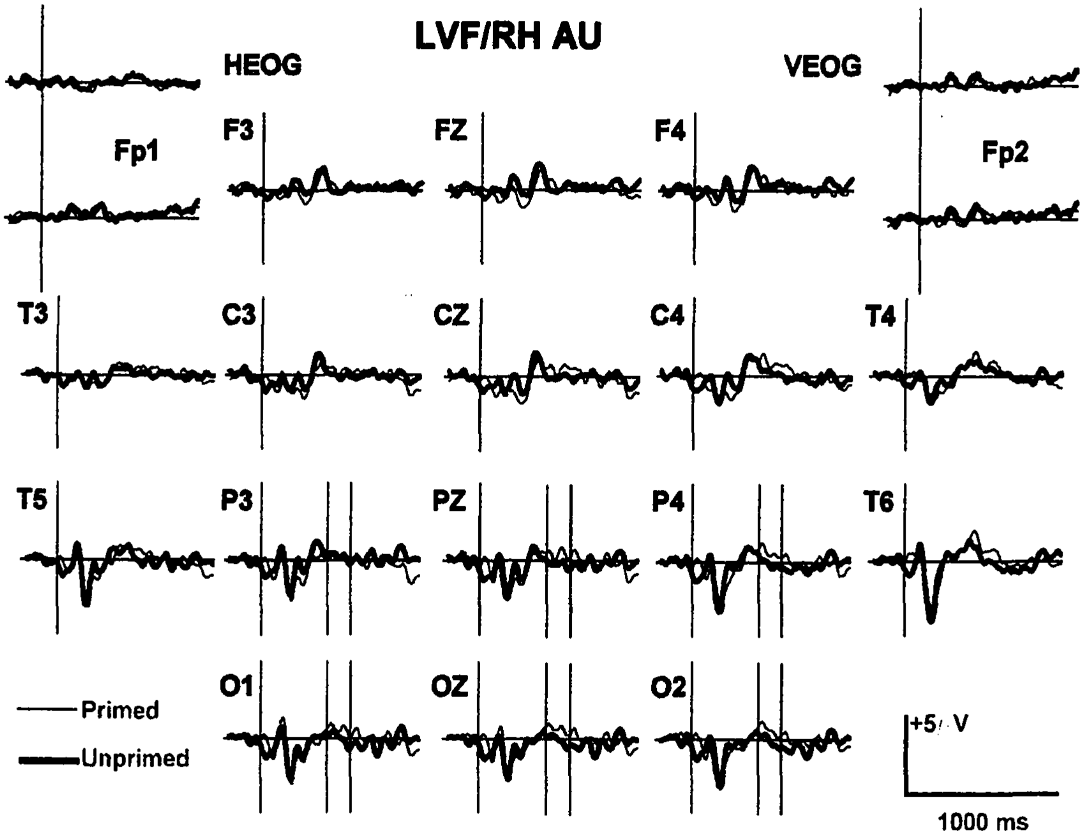

Figure 28: The grand averaged ERP response to the unattended target stimulus in Experiment 2 for the LVF/RH condition. Note that this stimulus was preceded by an attended prime.

Figure 29

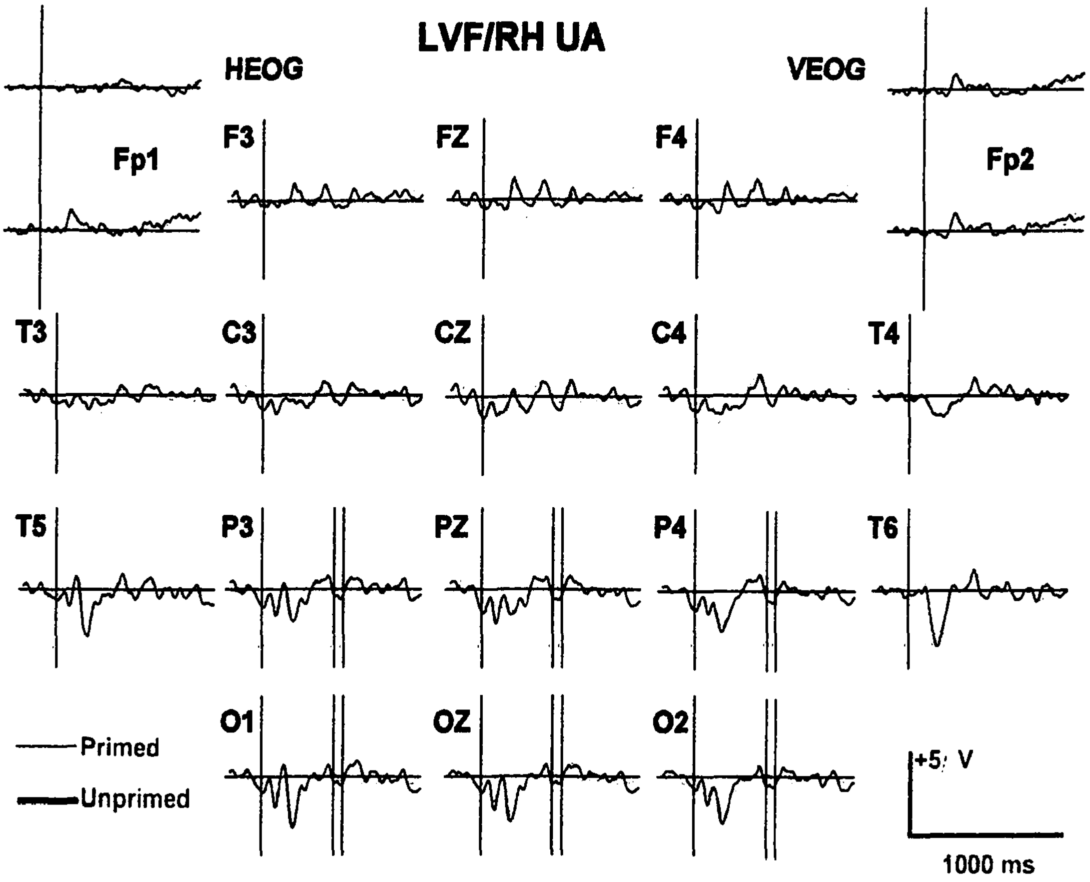

Figure 29: The grand averaged ERP response to the attended target stimulus in Experiment 2 for the LVF/RH condition. Note that this stimulus was preceded by an unattended prime.

Figure 30

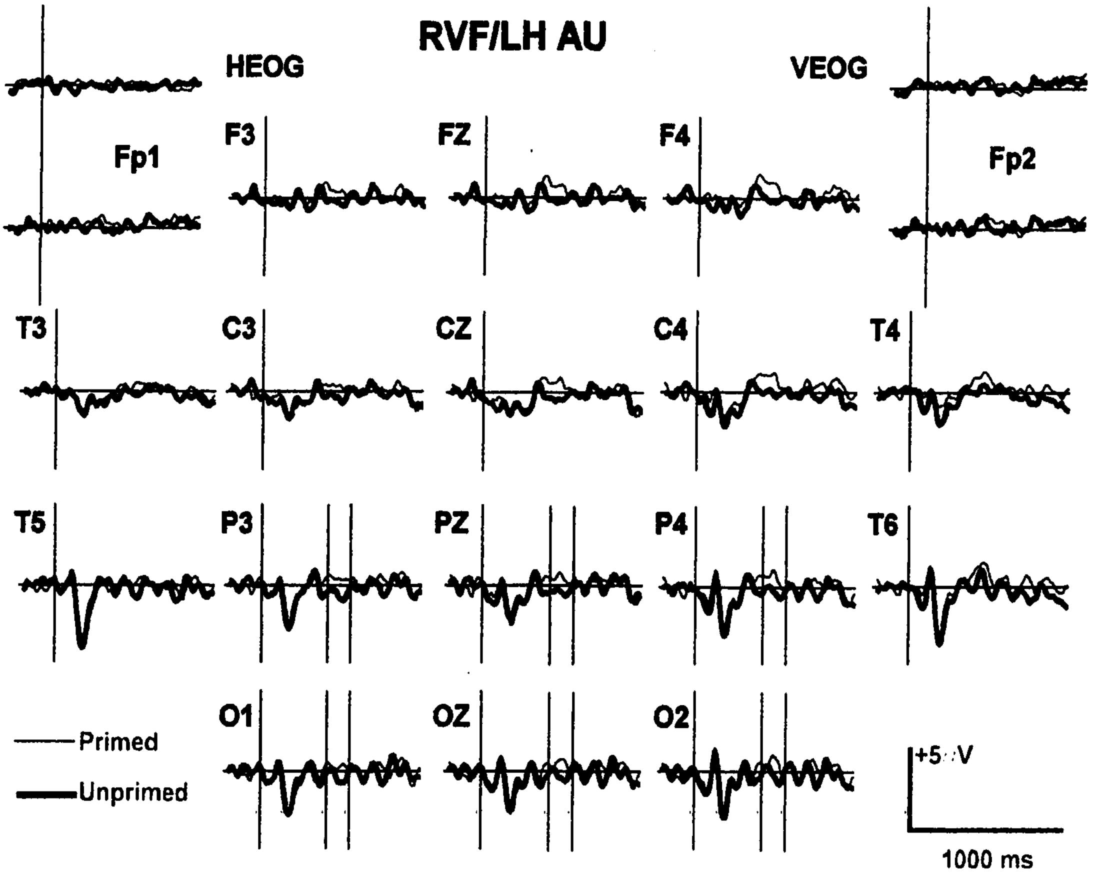

Figure 30: The grand averaged ERP response to the unattended target stimulus in Experiment 2 for the RVF/LH condition. Note that this stimulus was preceded by an attended prime.

Figure 31

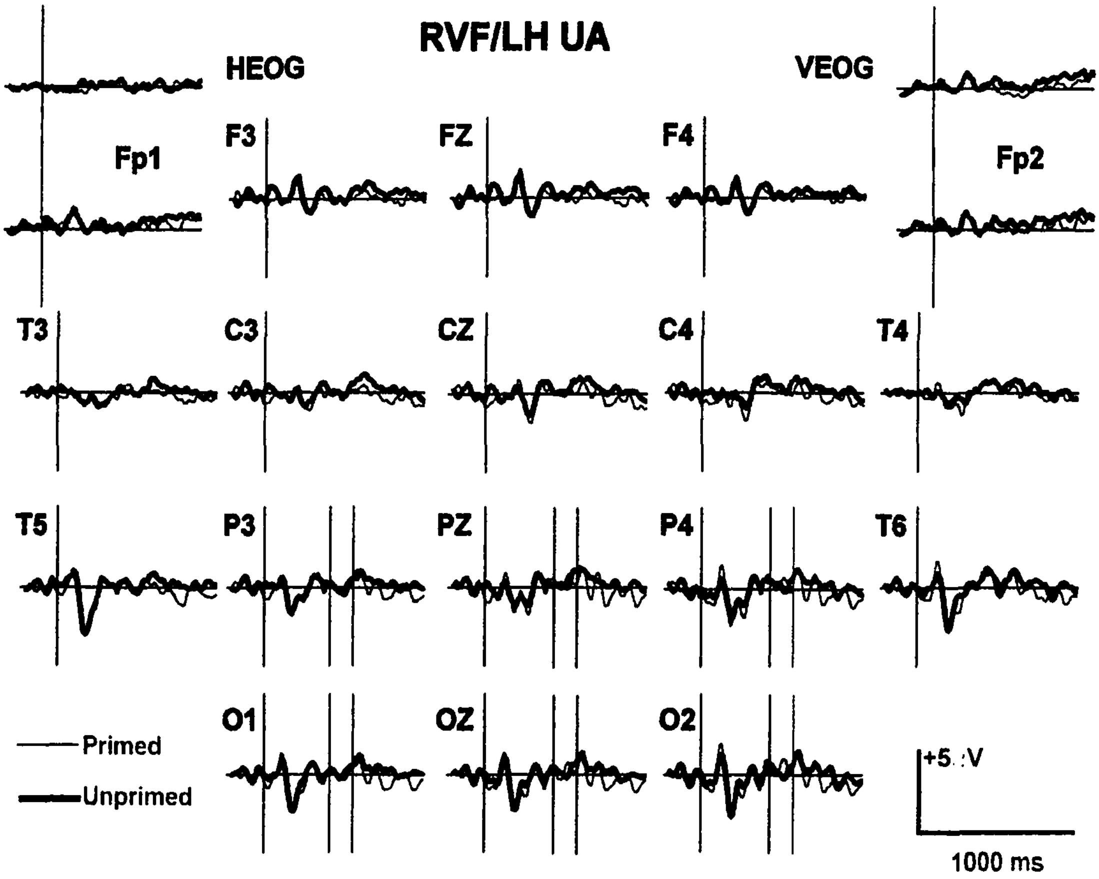

Figure 31: The grand averaged ERP response to the attended target stimulus in Experiment 2 for the RVF/LH condition. Note that this stimulus was preceded by an unattended prime.

Tables

Table 1

Mean Word Lengths and Frequencies For Targets

	LVF				RVF			
	A		UA		A		UA	
	P	UP	P	UP	P	UP	P	UP
LENGTH	5.20	5.70	5.43	5.50	5.38	5.77	5.10	5.70
FREQENCY	50.39	50.23	50.41	50.76	50.05	50.87	50.15	50.83

LVF = Left Visual Field
RVF = Right Visual Field
A = Attended
U = Unattended

UP = Unprimed
P = Primed

Table 1: Mean word lengths and frequencies for the target stimuli used in both Experiment 1 and Experiment 2.

Appendix A

PRIMED TRIPLETS

PRIME	TARGET	PROBE	PRIME	TARGET	PROBE
CUSHION	PILLOW	BED	LADDER	STAIRS	LIGHTER
RAKE	HOE	TOOL	PEN	PENCIL	WRITING
CLIFF	PRECIPICE	STEEP	DUSK	DAWN	TWILIGHT
SHOVEL	SPADE	DIG	KITTEN	PUPPY	PET
DIAMOND	RUBY	JEWEL	TABLET	PILL	MEDICINE
BASEBALL	SOFTBALL	GAME	RAT	MOUSE	RODENT
INFANT	BABY	DIAPER	HAT	CAP	HEAD
CHOCOLATE	VANILLA	FLAVORS	HAY	STRAW	FARM
FRECKLE	MOLE	BLEMISH	MAGAZINE	NEWSPAPER	READ
FENCE	GATE	PICKET	JUPITER	MARS	PLANET
WASHER	DRYER	CLOTHES	HAND	FOOT	BODY
ACROBAT	JUGGLER	CIRCUS	BELLY	STOMACH	GUTS
CHURCH	CHAPEL	CATHEDRAL	SATIN	SILK	FABRIC
RABBIT	HARE	BUNNY	BROOM	MOP	CLEAN
SEAL	WALRUS	ARCTIC	BOWL	DISH	FOOD
APPLE	PEAR	FRUIT	BACON	HAM	BREAKFAST
SCARF	TIE	NECK	ROOF	WALL	BUILDING
LAMP	LIGHT	SHADE	PISTOL	RIFLE	GUN
STREET	ROAD	PATH	ROCK	STONE	PEBBLE
SPIDER	ANT	INSECT	HAZE	SMOG	WEATHER
BARLEY	WHEAT	CEREAL	SNAIL	SLUG	SLIME
HOUSE	GARAGE	HOME	SCHOOL	COLLEGE	TEACHER
DUCK	GOOSE	FOWL	HALLWAY	CORRIDOR	PASSAGE
POT	PAN	COOKING	DAGGER	SWORD	STAB
TUNA	SALMON	FISH	GOLD	SILVER	METAL
TWIG	BRANCH	LEAF	SCOOP	SPOON	UTENSIL
HILL	MOUNTAIN	CLIMB	IRON	STEEL	METAL
BEARD	MUSTACHE	HAIR	DOOR	WINDOW	OPENING
CLOCK	WATCH	TIME	ROPE	STRING	KNOT
MOSQUITO	FLY	BUG	WOOL	COTTON	FABRIC
CHAIR	TABLE	KENNEL	ARM	LEG	LIMB
BALLERINA	DANCER	CANDLE	BREAD	ROLL	WITCH
BARBECUE	GRILL	RUFFLE	RECTANGLE	SQUARE	NUTSHELL
KEG	BARREL	CHORUS	OVEN	STOVE	NETTLE
OIL	GREASE	ICE-CREAM	OCTOPUS	SQUID	LAMPSHADE
DUNGEON	PRISON	SPARK	MONKEY	CHIMPANZEE	MELODY
BUTTER	MARGARINE	PREFIX	TANGERINE	ORANGE	EYE
CRADLE	CRIB	KNUCKLE	GARLIC	ONION	THUNDER
HOTEL	MOTEL	DUSTPAN	OAK	ELM	EGGS
CART	WAGON	LATITUDE	CHECKERS	CHESS	LENS
HORN	BUGLE	WINTER	ALLIGATOR	CROCODILE	LIGHTNING
MUSSEL	CLAM	STAMP	MONASTERY	CONVENT	TOASTER
PONY	HORSE	SHUTTER	LEATHER	SUEDE	RECORDING
BUFFALO	BISON	PLANET	STORM	TYPHOON	BURGER
PARCEL	PACKAGE	LEGEND	BRANDY	WHISKY	AXIS
HARBOR	BAY	CLEAN	GRAPE	CHERRY	BASS
BEE	WASP	FISH	SQUIRREL	CHIPMUNK	BUTTON
BUGGY	CARRIAGE	CHIMNEY	HEART	LUNG	PEACH
SALT	PEPPER	SONG	SWING	HAMMOCK	ZIPPER
CONCRETE	CEMENT	MOTHER	CRAYON	CHALK	PLUM
PIANO	ORGAN	FATHER	BRACELET	NECKLACE	FRIES
WHEEL	TIRE	COUNTY	BOOK	NOVEL	SINK
BEER	WINE	BATTERY	AIRPLANE	JET	SHERIFF
BOG	MUD	BEDROOM	RUG	CARPET	SCHEME
SHORTS	PANTS	TOMATO	NUT	BOLT	DOCTOR
MAGGOTS	WORMS	INDEX	SQUASH	PUMPKIN	NURSE
LIVER	KIDNEY	MATCH	LETTUCE	CABBAGE	STALL
MARKET	STORE	INTERVAL	PLUTO	NEPTUNE	PEPSI
MINK	FOX	PETER	JAM	JELLY	CANOE
NIGHTGOWN	PAJAMAS	PIE	TWEEZERS	PLIERS	SKIN

Appendix A continued

PRIMED TRIPLETS

PRIME	TARGET	PROBE	PRIME	TARGET	PROBE
BUSH	TREE	PLANT	ATTIC	BASEMENT	FISH
SOAP	DETERGENT	WASH	CYCLONE	TORNADO	FRINGE
LEMON	LIME	SOUR	CLARINET	SAXOPHONE	WOODWIND
SCALPEL	KNIFE	SILVERWARE	WAFFLES	PANCAKES	SYRUP
CURTAINS	DRAPES	SHADES	SHRINE	TEMPLE	WORSHIP
PLANK	BOARD	WOOD	POPE	BISHOP	RELIGION
SACK	BAG	LUNCH	DOG	CAT	PET
LETTER	NOTE	MAIL	TROMBONE	TRUMPET	MUSIC
GIN	VODKA	DRINK	SOLDIER	SAILOR	MILITARY
DIARY	JOURNAL	WRITE	SCISSORS	SHEARS	CUT
LION	TIGER	FELINE	CASHEW	PEANUT	SNACK
FINGER	THUMB	DIGIT	OCEAN	SEA	WATER
MILK	CREAM	DAIRY	SOFA	COUCH	SEAT
CRAB	LOBSTER	CLAW	CHICKEN	TURKEY	POULTRY
VAULT	SAFE	BANK	BOMB	MISSILE	EXPLOSION
LAWN	GRASS	MOWER	MUSTARD	KETCHUP	CONDIMENT
MANSION	CASTLE	MOAT	CAVERN	CAVE	DARK
TORTOISE	TURTLE	SHELL	SWAMP	MARSH	WET
PLATE	SAUCER	DINNER	THREAD	YARN	KNIT
OXYGEN	HYDROGEN	GAS	MUTTON	LAMB	MEAT
TRICYCLE	BICYCLE	CYCLE	SCREW	NAIL	HAMMER
NICKEL	DIME	COIN	GLUE	PASTE	STICKY
NEEDLE	PIN	SEW	CANYON	VALLEY	DEEP
PADDLE	OAR	ROW	COFFEE	TEA	DRINK
ASPHALT	PAVEMENT	SIDEWALK	UNDERWEAR	BRIEF	BRA
SWEATER	VEST	CLOTHING	CIGAR	PIPE	CIGARETTE
MOON	EARTH	PLANET	FROG	TOAD	AMPHIBIAN
STREAM	RIVER	WATER	MOTOR	ENGINE	TRAIN
RADIO	STEREO	MUSIC	BOOT	SHOE	LACE
POND	LAKE	WATER	CEILING	FLOOR	TILE
STOCKING	SOCK	ECHO	SNOW	SLEET	COLD
PENNY	CENT	TENNIS	BROTH	SOUP	FOOD
STOOL	BENCH	KING	BLANKET	SHEET	PUDDING
RAG	CLOTH	SERGEANT	SHARK	WHALE	PIONEER
GUITAR	BANJO	BRICK	TOWN	CITY	GIFT
TACK	STAPLE	GOLF	SUIT	TUXEDO	CANOPY
YACHT	BOAT	WEAPON	SUGAR	FLOUR	COMET
PIGEON	DOVE	QUEEN	COAT	JACKET	WELFARE
ARTERY	VEIN	BUS	BUCKET	PAIL	FLAMES
COAST	SHORE	FAUCET	TEAPOT	KETTLE	EXERCISE
STEAM	VAPOR	BONNET	ROBIN	SPARROW	SCENT
CABLE	WIRE	HOLLAND	MOOSE	ELK	EXIT
COCAINE	HEROIN	LANDSCAPE	BUREAU	DRESSER	SPLASH
ATLAS	MAP	STALK	DEER	ANTELOPE	TRAVELER
TENT	TEPEE	PRINCE	PARSLEY	SAGE	TIDE
ASTEROID	METEOR	BUNDLE	PRUNE	RAISIN	BEAN
BROCCOLI	CAULIFLOWER	HELICOPTER	TICK	FLEA	BOIL
DONKEY	ASS	SLANT	SAPPHIRE	EMERALD	WEED
CELLO	VIOLIN	TWIST	BATH	TUB	BORDERS
GLOVE	MITTEN	ENERGY	ROOSTER	HEN	FOUNTAIN
DRUM	CYMBAL	GERMS	BLOUSE	SHIRT	EMU
MOTH	BUTTERFLY	POLICE	FOG	MIST	FRICTION
BRUSH	COMB	PHOTOGRAPH	HANDBAG	PURSE	GECKO
ARENA	STADIUM	BUNDLES	HATCHET	AX	INCH
EAGLE	HAWK	STRANGER	TAVERN	INN	MEASURE
STATUE	MONUMENT	JANITOR	CABIN	COTTAGE	SLICE
REPORT	ESSAY	BULLDOZER	MUG	CUP	BOOM
FIELD	MEADOW	POPSICLE	VAN	CAR	HORNET
KNEE	ANKLE	CANNON	TRUNK	SUITCASE	VIPER
LIZARD	SNAKE	SKEIN	HUT	SHACK	MOLAR

Appendix A

continued

UNPRIMED TRIPLETS

PRIME	TARGET	PROBE	PRIME	TARGET	PROBE
SIEVE	FLAG	AMERICAN	WALNUT	TUBES	REDWING
LECTERN	BLIZZARD	COLD	ARMCHAIR	CORD	CARBOHYDRATE
LINGERIE	MOLASSES	STICKY	OVARY	STRAP	CUB
FRIGATE	LINOLEUM	SHIP	WHIRLWIND	MAIDEN	INSECT
ARMOR	LOG	KNIGHT	PALATE	TRUCK	ANIMAL
CASHMERE	LOCKER	KEY	CATALOG	MARBLE	TODDLER
SQUALL	ABACUS	COUNT	LICORICE	OUTFIT	PIG
TATTOO	CAROUSEL	CARNIVAL	PARACHUTE	SPONGE	ANNEX
PRAYER	ESCORT	DATE	PANDA	PERFUME	TYMPANI
GALLEON	SPACE	SHIP	LAUNDRY	MAPLE	BIRDS
TIMBER	PEOPLE	WOOD	PAW	MEAL	INSECT
GIRAFFE	DIAGRAM	ANIMAL	WHALING	BAMBOO	DELTA
GLASS	SAILING	SHIP	STEAMSHIP	KID	BABOON
LARYNX	MELON	HONEYDEW	KILT	PHYSICS	AVOCADO
SHIN	BRACES	BONE	LIMOUSINE	LID	CHAMELEON
BANANA	CAMEL	FRUIT	CARD	APRON	INSECT
HURRICANE	PRONGS	FORK	YOLK	OFFICE	THIGH
MAYOR	OWLS	HOOT	LOUNGE	POISON	BARRACKS
PACK	LODGE	SKI	JUICE	MOONLIGHT	SCALLOP
SIDE	VACCINE	FRONT	CARRIER	MOLD	FLOUNDER
DOLL	CRANBERRY	TOY	SEASONING	FAN	FISH
TUITION	GALLERY	ART	MORPHINE	LOOP	ACCORDIAN
MINT	UMPIRE	REFEREE	ANTIQUE	HONEY	EVERGREEN
SAUCEPAN	MOSS	GREEN	DINGHY	CARDINAL	BREAST
TOURIST	LACROSSE	CAMERA	SHREW	JAW	CENTURY
WAITER	GRAVE	SERVER	FREEZER	BRAIN	INSECT
YAWN	TONGS	SLEEPY	MALLARD	PIZZA	CLAY
MEMBRANE	BOWLING	ALLEY	CUTTER	SUNSHINE	WRESTLING
KOALA	MARYLAND	STATE	EMPIRE	TRAP	HARMONICA
TON	JURY	TRIAL	POTATO	HOSPITAL	EDITOR
AVALANCHE	KEEL	SHIP	JEANS	SPRAY	CARNIVORE
PAPRIKA	BASIN	SPICE	SCIENTIST	MIRROR	KAZOO
LICE	BOMBER	ITCH	BALLOON	GRAPH	SCAR
RACOON	EYELASH	EYEBALL	SANDWICH	WILLOW	THIGH
MIMOSA	POCKET	POUCH	WAVE	CHEESE	ANNEX
SALAD	VIKING	DRESSING	KEEPER	DECK	LASAGNE
KNOLL	SALIVA	SPIT	MERMAID	RULER	BIRD
LUTE	TANKER	SHIP	NEON	SHELLS	GERBIL
MERINGUE	OUTLET	PLUG	APRICOT	FORT	ANIMAL
GUST	BERRY	WIND	ABDOMEN	GIRL	NEPHEW
GORILLA	LOBBY	APE	POPCORN	BEAK	LEPER
LATEX	OFFICER	RUBBER	SKILLET	BLOCK	ANGEL
ASTROLOGY	TUNNEL	HOROSCOPE	RAINSTORM	STUDENT	BITTER
TWISTER	CANE	CANDY	TRAMP	GRAIN	TAMBOURINE
MASON	DOCK	PIER	JEEP	BARN	BOURBON
COUPON	LOLLIPOP	LICK	PANSIES	FILE	EDGE
SKIFF	VITAMIN	PROTEIN	BRONZE	POEM	COBRA
LEDGER	OYSTER	PEARL	SLOPE	LIBRARY	ANATOMY
CHIPS	LOTION	SNACK	MANGO	COMMA	HORSESHOE
MAGNOLIA	AIRPORT	PLANE	KITCHEN	READER	FORMULA
FOSSIL	DUCTS	DINOSAUR	MAHOGANY	SCALE	CUFFLINK
EMBLEM	LADYBUG	INSECT	SINGER	BLOOD	CALM
ALBUM	ROWBOAT	RECORD	MANHOLE	STEM	IVORY
ABSCESS	SCHOONER	SHIP	TROOPS	COW	KNOB
CACTUS	TOE	PLANT	SALOON	PARADE	ADD
JUTE	KANGAROO	ANIMAL	CLOSET	LIST	PROCESS
OGRE	GLACIERS	ICE	HERBS	FIST	RYE
BUTLER	LOOM	SERVANT	LANCE	STUDY	IVY
SCORPION	NAPKIN	STING	CONCERT	POWDER	GOSSIP
RAINCOAT	TERMITE	INSECT	CLOWN	THRONE	ASTHMA

Appendix A

continued

UNPRIMED TRIPLETS

PRIME	TARGET	PROBE	PRIME	TARGET	PROBE
BUMP	HOLDER	LUMP	TRAY	SKATING	FULCRUM
PICKLE	MINSTREL	MUSIC	LOIN	TIMER	POPLIN
CHIVES	TANK	FISH	YAWL	SHOP	PUPPET
CHASM	OTTER	BEAVER	POODLE	LIP	BOND
CORN	WHISTLE	COB	BOAR	CABINET	BEETLE
RODENTS	SOCCER	GOAL	ABBOT	HOUND	RICE
MIDWIFE	COLLAR	LAPEL	STEAMBOAT	LIMESTONE	DEACON
BROILER	MAILBOX	MAILMAN	FRAME	ATHENS	AGENCY
GOAT	ARCH	ANIMAL	DOLPHIN	COMPUTER	ALPS
CLASSROOM	MEDAL	TEACHER	RAINBOW	DIVER	PADDOCK
TEASPOON	SPRING	SUMMER	OVERCOAT	GARBAGE	COMBER
RABBI	MITTENS	JEW	FUNNEL	LINING	SHRIMP
SKEWER	MAIZE	KEBAB	ORE	DEW	WING
VAMPIRE	NARCOTICS	DRACULA	HOTDOG	PRINTER	VIRUS
BAR	MAMMOTH	DRINK	SAUSAGE	ALCOHOL	DESSERT
LOCUST	VOLCANO	LAVA	GNAT	BEETS	HOUSEWIFE
SUBMARINE	LASSO	COWBOY	TORRENT	DISTRICT	ADDER
GLAZE	MAKEUP	MASCARA	PINEAPPLE	FROST	FISH
VISA	COASTER	MASTERCARD	BEEF	MAINLAND	KERCHIEF
HELIUM	EYELID	EYEBALL	SAFFRON	HOLE	ANCESTOR
BUBBLE	MINER	BURST	PACKET	TAP	CHINOS
MARSHAL	DRUGS	ADDICT	FERRY	COUNTER	WEST
RAZOR	NECTAR	SHAVE	CRICKET	ACID	DUMPLING
LAUNCH	GOVERNOR	SHIP	CARP	PATIENT	AGATE
LINK	MAINE	STATE	GRIDDLE	RIBBON	SNAPPER
BOOKCASE	SHOWER	CLEAN	ROOT	LOCK	DOPE
CANISTER	TUGBOAT	SHIP	BEAM	MILL	SABLE
OINTMENT	LARDER	MEDICINE	BOTTLE	CARDBOARD	HERRING
PALETTE	SKUNK	STINK	FOLD	BREEZE	HADDOCK
BEACON	LINEN	FABRIC	RUGBY	GLIDER	MYTH
KIMONO	LATHE	JAPAN	POPPER	SUPPORT	BASSOON
DRIZZLE	LITTER	KITTY	ACRYLIC	GHOST	CAVIAR
ECLIPSE	AIRFIELD	PLANE	PETROLEUM	ICE	BINOCULARS
PLATTER	PEST	RODENT	PANEL	THROAT	CUFF
FREIGHTER	EYEBROW	EYEBALL	COOK	PILOT	XYLOPHONE
CLOAK	LIONESS	FELINE	FUEL	HISTORY	BOSTON
GALAXY	BARRIER	STAR	DILL	FOOTBALL	EXPRESS
HUSKY	CAFÉ	FOOD	WARRIOR	FACTORY	SARDINE
OUTLINE	GOURD	PAPER	MOORING	COURT	STUFFING
MUFFIN	PARAFFIN	BLUEBERRY	CROWD	JAR	PAGAN
STEAMER	DRAWER	CHEST	LIFEBELT	PARK	TYLENOL
LATCH	WRECK	KEY	NAPE	BATTLE	DANGER
VASE	COT	FLOWER	HOCKEY	SUPPER	PROCESSION
PLOW	KEYBOARD	FARM	MUSICIAN	SEAWEED	BEATER
SATELLITE	SMOKE	FIRE	SLED	CHART	MISER
CACHE	LUMBER	WOOD	RASPBERRY	TRACK	SALARY
MARTINI	SEED	PLANT	COCONUT	CALENDAR	CANARY
LADLE	LEOPARD	SPOTS	MAGNUM	SHOULDER	SHOW
ROCKER	FREIGHT	SHIP	PEACOCK	COLUMN	REVOLVER
DEN	LLAMA	ANIMAL	KEYHOLE	LIQUIDS	POSTER
MOOR	MAGICIAN	MAGIC	MANOR	LEVEL	BARK
BOTANY	POPPY	FLOWER	SPEAKER	BEAR	NATION
RANGE	MACARONI	NOODLE	GRINDER	CASE	ANSWER
GROOVE	BOSS	EMPLOYEE	BUTANE	ORCHARD	EAST
GINGHAM	PEAS	CARROTS	CHEEK	CLASS	ASP
HOOF	VINE	PLANT	LENTILS	BOX	IGUANA
LABORER	NET	FISH	CLIPPER	FAMILY	TOBACCO
MARLIN	DEPOSIT	BANK	BRITAIN	ROOM	NIECE
LOBE	CALCIUM	EAR	MANAGER	PAGE	BLONDE
ABBEY	DRAGON	FIRE	SURFING	MILE	DIMPLE

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