HEMISPHERIC INTERACTIONS AND EVENT-RELATED POTENTIALS
IN LATERALIZED STROOP AND STROOP ANALOG TASKS

DISSERTATION

Presented to the Graduate Council of the
University of North Texas in Partial
Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

By

Voyko Kavcic, DIPL

Denton, Texas

December, 1997

Classical Stroop stimuli and newly developed face/word Stroop analog stimuli were used to investigate hemispheric interactions in Stroop interference effects (SEs) and corresponding event-related potentials (ERPs). Lateralized stimuli were presented unilaterally and bilaterally as congruent or incongruent color strip-word or face-word pairs [to invoke right hemisphere (RH) and left hemisphere (LH) specialization, respectively, in the latter case]. The common finding for such tasks is that responses for the congruent condition are faster and more accurate than for the incongruent condition (i.e., the SE). A primary prediction is that the SE will be maximized when both the distractor and target components, or distractor alone, are presented to the specialized hemisphere (i.e., LH for words and RH for faces).

A total of 88 right-handed University of North Texas students participated in one of four experiments. Participants manually responded to one component of the stimuli (i.e., color, face, or word), while ignoring the other. Behaviorally, participants showed a robust SE across all experiments, especially for the face/word task with word targets. Findings from the face/word Stroop analog tasks also indicated that SEs were produced by selective attention to either faces or words, implicating a role for top-down (controlled) processes. Hemispheric asymmetries were observed only for bilateral
presentations of the face/word Stroop analog stimuli and did not differ for word versus face targets. The results suggest that the LH is less susceptible to interference from the RH than vice versa.

Electrophysiologically, anterior N1 and P1, posterior P1 and N1, N2, and P3 components were identified. A SE was found for P3 amplitudes, but not latencies, across all four experiments such that the congruent condition generated greater amplitudes than the incongruent condition, suggesting that the P3 is an index of task difficulty. Surprisingly, SEs were also observed for the early ERP components, albeit embedded in higher order interactions. Taken together, the ERP evidence suggests that there is no single locus of the SE, and instead, the SE appears to be distributed over several stages of information processing.
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Little did I realize what my advisor and committee chair Dr. Jeff Clarke meant when he said "with your dissertation you earn a doctoral degree". Having completed my dissertation I now know and understand what he meant. The dissertation process has been arduous, but rewarding, during which I have learned much more than I ever anticipated. Working closely with Dr. Clarke, I greatly advanced my theoretical and applied research skills and, especially with respect to the investigation of hemispheric interactions. It has been my privilege to work with Dr. Jeff Clarke, and it was my pleasure when we debated or lively disputed the outcomes from the dissertation research. Therefore, I wish to thank Dr. Jeff Clarke for his expert help and guidance in theoretical, methodological, linguistic, and technical issues. Without his outstanding knowledge and enthusiasm I would not have been able to complete the dissertation project. The next most valuable person throughout the dissertation process was my wife, Bonnie, whom I thank for her valued and continuous encouragement, editing help, and moral support.

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CHAPTER I

INTRODUCTION

Overview

The main focus of this research project is on hemispheric interactions in the interference effects and corresponding event-related potentials (ERP) produced by the classical Stroop task as well as a Stroop task analog. In the case of the classical Stroop task and Stroop analog task, an interference effect occurs when the processing of one dimension/stimulus of a compound stimulus interferes with the processing of another dimension/stimulus. Detailed descriptions of the interference effects or so called Stroop effect (SE) will follow in the introduction section.

The goals of this research are threefold. The first is to further elucidate the nature of the SE by contrasting findings from different experimental manipulations of Stroop and Stroop analog tasks. The second is to advance understanding of hemispheric asymmetries in the performance of the lateralized Stroop and Stroop-like tasks. And the third is to further the knowledge of the neurophysiological basis of the Stroop phenomenon.

The introduction section will consist of three sections. In the first section, the Stroop task and a new Stroop analog task will be introduced and the major models accounting for the SE will be presented. A discussion of the interhemispheric paradigm
and a major model explaining hemispheric interactions will follow in the second section.

Also included in this section will be summaries of studies that have employed lateralized Stroop tasks, a discussion relating to the inconclusive evidence of hemispheric asymmetries for such tasks, and some proposed research options. The concluding section of the introduction will include a review of the literature concerning the neuroanatomical and neurophysiological basis of the SE. The primary focus of the last section will be on electroencephalographic (EEG) research.

List of abbreviations:

VF = visual field  
EEG = electroencephalography  
LVF = left visual field  
RVF = right visual field  
LH = left hemisphere  
RH = right hemisphere  
SE = Stroop effect  
ERP = event-related potentials  
BVF = bilateral visual field  
PET = positron emission tomography

Introduction to the Stroop Task

In 1935, John Ridley Stroop published an article entitled "Studies of interference in serial verbal reaction" in which he introduced what is now called the Stroop task. The Stroop task has become one of the most widely used tasks in psychological research. In its 60 year history, the Stroop task has been used in over 1000 studies, particularly in the realm of cognitive psychology (MacLoad, 1991). The task’s reliable and robust effects have made it particularly attractive to researchers. Despite its widespread use, an adequate model accounting for all the Stroop phenomena has yet to be proposed.
The Stroop task is very simple in nature: it consists primarily of the names of certain colors written in different colored inks. In one version of the task, participants are required to respond to two different types of stimuli: congruent stimuli (e.g., the name of the color RED written in red ink) and incongruent stimuli (e.g., the name of the color BLUE written in green ink). The task of the participant is to respond as quickly and as accurately as possible, indicating the color of ink in which the color name is written. The word itself is to be ignored. The response to the task of color naming can be either vocal or manual.

The prevalent finding from previous research is faster responses to congruent than to incongruent stimuli which is considered the main part of the SE. When the task includes neutral stimuli (e.g., a string of colored Xs, a color neutral word, or color patches), a response time disadvantage for incongruent stimuli versus neutral stimuli is considered an interference effect. On the other hand, a response time advantage of congruent over neutral stimuli is considered a facilitation effect. Both interference and facilitation are considered to be components of the SE. MacLeod's (1991) review of many Stroop studies indicates that the interference effect is larger and more reliable than the facilitation effect and accounts for the major component of the SE. The facilitation effect has been found to be quite unstable and negligible. This means that there is typically no significant difference in response times and accuracies between congruent and neutral stimuli.

When neutral stimuli are omitted from the Stroop task, some authors (e.g., MacLeod, 1991; Weekes & Zaidel, 1996) consider the difference between the
incongruent and congruent stimuli as a measure of the SE. Thus, the congruent stimuli are equated with the neutral stimuli. David (1992), on the other hand, termed the difference between the incongruent and congruent trials as a combined Stroop effect. The impact of omitting neutral stimuli for the current research project is important in that it will allow for more congruent and incongruent trials. A greater number of congruent and incongruent trials (i.e., approximately 50 trials of each stimuli) is of crucial importance from the EEG data collection point of view because of the requirement of a large number of trials per condition for ERP averaging procedures (e.g., at least 40 artifact free ERP epochs for averaging).

Throughout the history of the Stroop task, numerous modifications have been made. Although used primarily in the visual sensory modality, the Stroop task can be modified for the auditory modality. Primary modifications have been made relating to the nature of the Stroop stimuli and the type of response modality (e.g., vocal vs. manual). Several modifications of the Stroop task are of interest to the present research proposal. One such modification is the use of nonintegrated stimuli in which the color word and colored strip are spatially separated. Another modification of interest to the current research proposal is the use of integrated line drawings of objects and words (e.g., a line drawing of a banana in which different words can be embedded) or nonintegrated line drawings of objects and words (e.g., line drawing of a banana next to a word). With this modification, the stimulus is congruent when the word denotes the same meaning as the line drawing, and the stimulus is incongruent when the word does not match the line drawing (e.g., a line drawing of a banana with the word APPLE either embedded or
spatially separated). The participant’s task is to name the line drawing as quickly and accurately as possible. The picture-word stimuli are called Stroop analog stimuli or Stroop-like stimuli (MacLeod, 1991).

MacLeod (1991) reported that similar patterns of performance, including the interference effect, have been found with picture-word analogs as compared to performance with the classic Stroop stimuli. This means that the incongruent word printed inside the line drawing interferes with the picture naming while the congruent word does not interfere with picture naming. According to MacLeod (1991) one of the advantages of the picture-word stimuli is that these stimuli allow more flexibility in manipulations of the content of the stimuli (e.g., semantic relationship between the picture and the word) than classical color-word stimuli.

A newly developed Stroop-like task will be utilized in one of the experiments of the this study that will consist of nonintegrated photographs of a prototypical male, female, and baby face and the words MAN, WOMAN, and BABY. Consistent with the Stroop paradigm, participants will in one experiment be required to ignore the word, and, as accurately and as quickly as possible identify the photograph as either a man's, woman's, or baby's face.

In summary, typical Stroop tasks are comprised of stimuli that have two components: one component is a word, the other component may take a variety of forms (color, line drawing, etc.). The components are paired in the task as either compatible or incompatible. Because of the interference effect, response times to incompatible
components are greater than response times to two compatible components. Explanations of how and why this phenomenon occurs will be discussed in the following section.

Models Accounting for the Stroop Effect

A substantial number of studies have been conducted to elucidate the conditions necessary to produce the SE. Stroop (1935) attributed the interference effect to more effective associations between the word stimuli and reading responses than between the color stimuli and naming responses. Stroop concluded: "Since these associations are products of training, and since the difference in their strength corresponds roughly to the difference in training in reading words and naming colors, it seems reasonable to conclude that the difference in speed in reading names of colors and in naming colors may be satisfactory accounted for by the difference in training in two activities." (pp. 659-660).

Attempts by researchers to uncover mechanisms and information processing loci related to the SE have lead to the proposal of several models. Most models have proposed that the mechanism responsible for the SE is associated with differing processing rates of the attended dimension (color) of the Stroop stimulus relative to the processing rate of the ignored dimension (word). Two schools of thought exist regarding the loci of the SE: the school that assumes the SE occurs at an early locus in the information processing, and the school that assumes a later locus.

According to Hock and Eget's early-stage model (Dyer, 1973b), the interference or locus of the SE occurs in the early perceptual or encoding stage as a result of different color encoding for the incongruent and congruent stimuli; perceptual encoding of the
color for the incongruent stimuli is slowed by incompatible information from the colored word. According to Dyer (1973b) and MacLeod (1991), Hock and Eget's perceptual-encoding model holds little promise due to insufficient experimental support. Consequently, this model has not been embraced by researchers in the field.

According to the second school of thought, the SE occurs much later, either in the decision making or response-production stage. Within this school of thought, there are two existing models, the relative speed of processing model and the automaticity model.

According to the relative speed of processing model (MacLeod, 1991), words are read faster than colors are named. Not only does the difference in speed of processing account for the SE, but word reading and color naming are competing for response primacy. Thus, in incongruent conditions, the word is first available for responding but it must be suppressed/inhibited in order for the slower color naming response to be executed. The time consumed by inhibition basically represents the interference effect. Similarly, facilitation occurs because the end processing for both dimensions is the same; therefore, the production of the response is based on whichever code arrives first to the response execution stage. The relative speed of processing model further assumes that there are two parallel channels for processing each dimension of the Stroop stimuli, but that there is a single or limited capacity response channel into which one of the two codes can be admitted. Priority of admission into the response channel, according to MacLeod, is determined by the speed of processing. Metaphorically speaking, this model can be compared to a horse race; the two processes, word reading and color naming, compete for control of the final output. In the incongruent condition, the horse race becomes a "fixed"
race in that the faster horse, word reading, must be held back so that the slower horse, color naming, can win.

The relative speed of processing model has been endorsed by Dyer (1973b) but only if coupled with a selective attention failure (i.e., participants cannot ignore the color word). Using empirical results from his comprehensive review, MacLeod (1991) proposed 18 criteria that must be met by any model of the SE to adequately explain the phenomenon. Based upon those criteria, MacLeod (1991) discarded the relative speed of processing model because it fails to account for experimental manipulations of stimulus onset asynchrony (SOA) and because it does not account for the practice effect for Stroop task outcomes. According to the relative speed of processing model, interference should be always asymmetrical: the faster dimension should always interfere with the slower one. However, experimental findings related to the reverse SE, in which, after extensive practice, the irrelevant ink color interferes with word reading, are rarely obtained and do not depend only on relative speed of processing of the two components (MacLeod, 1991). Furthermore, presenting the slower dimension (e.g., color patch or line drawing) before the faster component (i.e., word) does not produce the expected reverse interference effect. From the focus of the present proposal, the relative speed of processing model would predict greater interference when Stroop stimuli are presented to the left, rather than the right, hemisphere due to left hemisphere (LH) specialization for reading.

The basic assumption of the automaticity model is that color naming draws more attentional resources than does reading the irrelevant word. Word reading is automatic and requires little or no attention because reading is such a common, over-learned
activity; furthermore, because word reading is automatic, it is also obligatory. On the 
other hand, naming ink colors is less automatic and, consequently, not obligatory; color 
naming requires conscious attention. Therefore, the interference in the Stroop task occurs 
because the words are read automatically, without a conscious decision, while color 
naming requires more attentional resources; the more automatic process interferes with 
the less automatic process. The automaticity model, like the speed of processing model, 
predicts a greater interference when the incongruent Stroop stimuli are projected to the 
LH, since reading is presumably more automatic in the LH than in the right hemisphere 
(RH). MacLeod (1991) contends that the automaticity model, if considered as a 
continuum rather than as an all-or-none concept, could be "potentially viable, but is in 
need of greater specification and more stringent tests" (p. 190). In terms of greater 
specifications, MacLeod refers to the more stringent and controllable measures of 
automaticity (e.g., dual task paradigm) and factors contributing to automaticity (e.g., 
learning history, practice).

In this proposal I intend to investigate hemispheric asymmetries in the processing 
of the lateralized classical Stroop task and a new analog of the Stroop task. The 
remainder of the introductory chapter will, therefore, be focused on hemispheric 
interaction models, research related to lateralized classical Stroop stimuli and picture-
word Stroop-like stimuli, as well as lateralized face tasks studies, and the 
neuroanatomical and neurophysiological bases associated with the SE.
Hemispheric Interaction Models

Hemispheric interaction models reviewed in this research study will be addressed only from the perspective of the lateralized behavioral techniques. Lateralized behavioral techniques are based upon the knowledge of neuroanatomical pathways and brain structures involved in sensory and motor processing. With the exception of the olfactory sensory modality, the sensory neural pathways are crossed; stimuli presented to the left side are projected to the RH and vice versa. For example, in the visual modality, tachistoscopic presentation of a left visual field (LVF) stimulus is initially transmitted to the RH, while stimuli presented to the right visual field (RVF) are projected to the LH. As with sensory processing, motor processing is characterized by neuronal pathway crossings. For manual responses, response execution is initiated in the contralateral side of the brain in relationship to the response hand.

Thus, by knowing the contralateral crossings of neuronal pathways of the sensory as well as motor processes with respect to the inputs and outputs, it is possible to manipulate input and output parameters and infer about differences in hemispheric processing. Based on the differences between hemispheric performance of a lateralized task, hemispheric asymmetries can be measured. Examination of performance patterns from lateralized tasks has been instrumental in allowing researchers to make inferences about functional hemispheric asymmetries. On the basis of behavioral hemispheric asymmetries, hemispheric specialization models have been proposed. According to these models, the two cerebral hemispheres are structurally and functionally distinct (Zaidel, 1983). According to Zaidel, the two hemispheres function by-and-large
independent of one another, and each is relatively specialized: the LH is superior at verbal processing, although the RH has the capacity for certain simple verbal processing (processing of letters and concrete nouns); the RH is superior for visuo-spatial processing. Performance of a specific task which can only be processed by one hemisphere is referred to as exclusive hemispheric specialization (e.g., dichotic listening to consonant-vowel syllables).

Initial investigations with the lateralized behavioral techniques can be traced back to the work of Franz during the 1930s, and to the experimental work of the McGill group in the 1950s (Zaidel, 1983). The major thrust of the activity came during the 1960s with the work of Kimura, Geschwind, and particularly with Sperry who, along with his graduate students and collaborators, worked with split brain patients (Zaidel, 1983). Full credibility for the laterality paradigm and hemispheric specialization came from experimental studies conducted on patients who received cerebral commissurotomy (i.e., split brain patients) for the treatment of intractable epilepsy (Zaidel, 1983).

Research with split brain patients also gave rise to an interest in functions of the corpus callosum. The corpus callosum serves as the primary channel for transfer of information between the two hemispheres. The transfer of information has measurable functional characteristics (e.g., transfer time and degradation of information during transfer of information from one hemisphere to another as reflected by decreased accuracy). Thus, knowledge of the functions of the corpus callosum has derived primarily from experiments with split brain patients. Paradoxically, it was the lack of
the corpus callosum in split-brain patients that created an interest in hemispheric interactions.

Based upon laterality findings in split brain individuals and normal individuals, Zaidel (1983, 1995; Zaidel, Clarke, & Suyenobu, 1990) proposed a model of hemispheric interactions. One of the basic assumptions of this model is that "each hemisphere constitutes an independent cognitive system with its own sensations, perceptions, cognition, memory, language, attention, and consciousness" (Zaidel, 1995, p. 491). The individual hemispheres, however, are able to function either independently or in cooperation with the other one. The degree of hemispheric interaction varies with the type of processing and can be conceptualized as being on a continuum with one end representing complete hemispheric independence and the other end of the continuum representing maximal dependency. From the perspective of hemispheric specialization the continuum ranges from absolute hemispheric specialization to relative hemispheric specialization and/or nonexistent hemispheric specialization.

According to the Zaidel model of hemispheric interactions (Zaidel, 1983, 1990) three possible types of interactions exist between the two hemispheres. The first type is callosal relay in which a task is completely performed in only one hemisphere. Therefore, callosal relay is required when the stimulus is initially projected to the nonspecialized hemisphere. For example, in dichotic listening to consonant-vowel syllables, the LH is exclusively specialized for the phonetic processing. Therefore, left ear inputs must be transferred across the corpus callosum to specialized processing
Figure 1.1

Schematic representation of a continuum for hemispheric interaction

<table>
<thead>
<tr>
<th>Hemispheric independence</th>
<th>Absolute hemispheric dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independence</td>
<td>Dependence</td>
</tr>
<tr>
<td>Relative hemispheric specialization</td>
<td></td>
</tr>
<tr>
<td>Direct access task</td>
<td>Callosal relay task</td>
</tr>
</tbody>
</table>

centers in the LH in order for the task to be successfully performed. The transfer of information from the nonspecialized hemisphere to the specialized one is reflected in terms of prolonged reaction times and decreased accuracy. The differences between the lateralized conditions indicates the degree of callosal or interhemispheric transfer of information.

For normal individuals performing a dichotic listening task to CVC syllables one would expect a main effect for Ear, such that the right ear-LH demonstrates better performance than left ear-RH (see Figure 1.2). An interaction between the laterality factor (e.g., ear) and a task factor (e.g., stimulus quality) would not be expected, indicating a lack of a processing dissociation. That is, the right ear-LH will show approximately an equal advantage as compared to the left ear-RH regardless of the task condition (i.e., degraded vs. masked stimuli). For split brain patients, however, stimuli presented to the nonspecialized hemisphere cannot be fully processed, since
direct cortical transfer of information between the two hemispheres is not possible without a corpus callosum. Consequently, the laterality effect for a callosal relay task is much greater in split-brain patients than in normal individuals. In terms of correlation, the callosal relay model predicts a high positive correlation between the processing of the left ear and right ear measures since a single hemisphere is performing the task.

With the second type of hemispheric interaction, direct access, a task can be performed by either hemisphere, independently of the other hemisphere. For example,
for a lexical decision task, in which a participant has to identify a string of letters as a word or a nonword, the stimuli are flashed to the RH or LH from contralateral VFs. Previous findings indicate that each hemisphere can perform this task independently of the other (Zaidel, 1983, 1990). Furthermore, for this particular task there is better performance for RVF than for LVF stimuli, which is evidence for LH specialization for this task. When split brain patients perform a direct access task, they demonstrate laterality effects that are the same as for normals (Zaidel, 1983, 1995). According to Zaidel, many of the lateralized tasks fall into this category of hemispheric interaction. Statistically speaking, there should be little or no correlation between the two hemispheres across trials, since it is assumed that each hemisphere has its own processing strategy and resources. On the other hand, there may or may not be a significant main effect of VF, however there should be a statistically significant interaction between VF and Condition (e.g., in the case of lexical decision task words/nonwords) indicating the degree of hemispheric specialization for each level of Condition (see Figure 1.3). The interaction between the laterality factor (i.e., VF or ear) with the task factor (i.e., congruent/incongruent stimuli, low/high complexity) is labeled as a "processing dissociation".

With the third type, interchangeable access or hemispheric cooperation, hemispheric cooperation is required for the performance of a task (Zaidel, 1995). For such a task, one hemisphere may possess the capacity to process a particular stage of information processing and the other hemisphere may possess the capacity to process a different stage of information processing. Such a task, then, may require cooperation
and interaction between the two hemispheres in order to process the task completely and successfully. A similar pattern of hemispheric interaction may be observed when optimal performance is required to complete a task with the greatest degree of functional economy: with the cooperative effort of the two hemispheres the task can be performed better as compared to the performance of a single hemisphere (Banich, 1995).
The callosal relay and direct access tasks are at the opposite ends of the hemispheric interaction continuum model: direct access indicates hemispheric independence, while callosal relay, by necessity, incorporates hemispheric cooperation. The interchangeable or hemispheric cooperation tasks range between the two poles of the hemispheric continuum model previously discussed. Zaidel (1990) has posed questions relating to the stage of information processing in which hemispheric interaction might occur: earlier or late in the information processing. He has also considered the possibility of shifts between the two types of hemispheric interactions: shifts from callosal relay to direct access and vice versa. Zaidel (1990) concluded that, depending upon the nature of the task presented, hemispheric interactions may occur at any stage of the information processing.

With regard to hemispheric interactions, Banich and Shenker (1994) has been interested in what she terms the binding problem. The binding problem is described as a unified psychological experience despite the continuous input from a multitude of internal and external sources. According to Banich, separate brain structures are continuously and simultaneously involved in diverse information processing to allow for the input to be integrated into a unified, coherent experience. Lateralized stimulus presentations, and hence lateralized hemispheric processing, may be considered a special case of the binding problem. According to Banich, questions still remain as to how the two hemispheres interact in order to produce a unified and coherent psychological experience. More specifically, how do the two hemispheres interact
during lateralized task presentations in order to correctly respond to the task’s demands?

Banich (1994; Banich & Shenker, 1995) has presented behavioral criteria for making more reasonable inferences about interhemispheric processing or interhemispheric interactions. Banich contended that interhemispheric processing can be inferred only by direct comparison of unilateral with bilateral trials. Unilateral trials serve as a baseline for bilateral trials. Additionally, information of hemispheric asymmetries is also needed to make inferences about hemispheric interactions. It is the within-hemispheric condition or unilateral trials that provide the evidence about hemispheric asymmetries. Statistically speaking, hemispheric interactions would be supported if the between-hemispheric condition or bilateral trials interact with unilateral trials on some other experimental factor. For example, in accordance with Banich’s propositions, for the Stroop task there should be an interaction between Stimulus type (i.e., unilateral/bilateral presentations) and Condition (i.e., congruent/incongruent stimuli).

Having reviewed the theoretical models of hemispheric asymmetries and interactions, a review of studies using the lateralized classical Stroop task will follow. An attempt will be made to relate the findings of these studies to the previously discussed models of hemispheric asymmetries and interactions.

**Lateralized Stroop**

A number of studies have been conducted using the lateralized paradigm with Stroop stimuli. Although many studies were designed to test hypotheses directly
related to the lateralized paradigm, others had hypotheses not directly related to the lateralized paradigm [e.g., Dyer (1973a): scanning versus hemispheric asymmetry; Hatta (1981): Kanji versus Kana processing; Franzon & Hugdahl (1986): performance of dextrals versus sinistrals], but have made statements about and drawn conclusions about hemispheric asymmetry. The focus of this section is to review those studies in which the traditional Stroop stimuli, in integrated or nonintegrated forms, were used in a lateralized manner with either unilateral or bilateral presentations.

As discussed previously, in the lateralized paradigm, hemispheric asymmetry is indicated by a main effect of VF and/or a VF X Condition (i.e., congruent and incongruent stimuli) interaction. While the main effect of VF indicates hemispheric independence and/or superiority (e.g., in lexical decision task there is an advantage of the LH), in the case of the Stroop task the interaction indicates that the interference effect is different for each VF. According to the model of LH dominance for verbal processing, one would expect that the interference effect would be greater for the LH than for the RH. That is, it will take longer for the participant to respond to the incongruent stimuli presented in the RVF as compared to the presentation of the same stimulus to the LVF because it is assumed that the verbal processing, which is superior in the LH, will interfere with color naming.

Studies Failing to Find Hemispheric Asymmetries

In a comprehensive review of the literature relating to the SE, Dyer (1973b) summarized a not previously published study in which he and Harker presented integrated Stroop stimuli to the LVF or to the RVF at two different eccentricities: 45
min or 2 degree of eccentricity. This initial study failed to demonstrate hemispheric asymmetries for lateralized Stroop stimuli.

The earliest study utilizing the lateralized presentation of nonintegrated Stroop stimuli was that of Dyer in 1973. He presented the names of colors in black ink and colored patches that were positioned vertically 2 degree from the fixation point such that the word appeared in one VF and the patch appeared in the other VF. In other words, nonintegrated - spatially separated Stroop stimuli were presented simultaneously to both VFs. The participant's task was to name the color of the colored strip. Using this procedure, Dyer tested a scanning hypothesis that postulated that stimuli presented to the left of the fixation point are processed faster than stimuli presented to the right of the fixation point due to a learned readiness to report from the left to the right acquired through reading. The competing hypothesis was left hemispheric superiority for verbal processing. Dyer's scanning hypothesis would be supported if a greater SE is produced when the word is presented in the LVF and the color in the RVF while the left hemispheric verbal processing hypothesis would be supported by the reverse pattern. Dyer found facilitation and interference effects in each VF, but did not find statistically significant differences between the VFs. Based upon these results, Dyer rejected the scanning hypothesis and he also failed to find support for the hemispheric asymmetry hypothesis. Despite Dyer's failure to find hemispheric asymmetries in a lateralized Stroop task, his findings demonstrated the occurrence of the SE in a lateralized paradigm and also demonstrated the usefulness of nonintegrated Stroop
stimuli. An additional contribution of Dyer's work was that it served as a springboard and impetus for further research using lateralized Stroop and Stroop-like stimuli.

In accordance with Dyer's findings, several researchers, using either integrated or nonintegrated Stroop stimuli, also failed to find a greater interference effect in the LH than in the RH (Bertke & Brown, 1996; David, 1992; Fuentes & Ornels, 1993; Hatta, 1981; Long & Lyman, 1987; Simon, Paullin, Overmyer, & Berbaum, 1985; Warren & Marsh, 1978). The findings of each of these studies will now be discussed in turn (See Table 1.1).

Warren and Marsh (1978) investigated the level of automaticity in performing the lateralized Stroop task. Participants were required to match the color name and the ink color of the lateralized integrated Stroop stimuli (i.e., same/different response type) by keypress responding. Although an overall SE was found, there was no difference in interference between the RH and the LH.

Hatta (1981) conducted two studies relating to hemispheric asymmetries in linguistic processing by using two types of Japanese characters: Kana (phonetic symbols) and Kanji (non-phonetic symbols or logographs). Hatta presented the two types of the Japanese characters laterally in both VFs in a Stroop-like fashion. Participants were required to respond manually identifying the color of the stimulus as fast and as accurately as possible. According to Hatta (1981), previous research has shown that the RH is superior in processing Kanji symbols, while the LH is better for Kana characters because Kana characters resemble the Latin alphabet. Hatta did not find hemispheric asymmetries in the performance of the phonetically based Kana characters. However,
Table 1.1

List of studies using lateralized (unilateral and bilateral) classical Stroop stimuli that failed to find hemispheric asymmetries.

<table>
<thead>
<tr>
<th>Study</th>
<th>Stimuli</th>
<th>Response</th>
<th>Subjects</th>
<th>DV</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uni/Bil</td>
<td>Ver/Hor</td>
<td>Man/Voc</td>
<td>M/F</td>
<td>RT/Ac</td>
</tr>
<tr>
<td>Dyer, 1973</td>
<td>Bil</td>
<td>Ver</td>
<td>Voc</td>
<td>M</td>
<td>RT</td>
</tr>
<tr>
<td>Hatta, 1981</td>
<td>Uni</td>
<td>Hor</td>
<td>Man</td>
<td>M, F</td>
<td>RT, Ac Kanji showed asym.</td>
</tr>
<tr>
<td>Simon, Paulin, Overmeyer, Berbaum, 1985</td>
<td>Uni</td>
<td>Hor</td>
<td>Man</td>
<td>M, F</td>
<td>RT</td>
</tr>
<tr>
<td>David, 1992</td>
<td>Bil</td>
<td>Hor</td>
<td>Voc</td>
<td>M, F</td>
<td>RT</td>
</tr>
<tr>
<td>Fuentes &amp; Ortells, 1993</td>
<td>Uni</td>
<td>Hor</td>
<td>Voc</td>
<td>M, F</td>
<td>RT</td>
</tr>
<tr>
<td>Bertke &amp; Brown, 1996</td>
<td>Bil</td>
<td>Ver</td>
<td>Voc</td>
<td>M, F</td>
<td>RT</td>
</tr>
</tbody>
</table>

? = no information available
Hatta (1981) found hemispheric asymmetries for the Kanji characters indicating that the RH was more prone to the SE than the LH.

Simon et al. (1985) used lateralized Stroop stimuli while controlling for handedness and gender. Left and right handed males and females were asked to identify the word and the color dimension of the Stroop stimuli by key pressing in two separate experiments. Results yielded no VF X Condition effect either in the color naming or word processing mode despite the finding of a reliable SE in each VF. Using nonintegrated Stroop stimuli with the color stimulus presented foveally as a target and the word presented parafoveally as a distractor, Fuentes and Ortells (1993) failed to find a reliable VF/hemispheric effect. This suggests that there was similar processing of the word distractor in both hemispheres.

The first replication of Dyer's 1973 study with nonintegrated Stroop stimuli was conducted by David (1992). He presented vertical color names in white ink and vertical color strips. The nonintegrated Stroop stimuli were either presented both within a VF (i.e., unilateral presentations) or each component was presented to the separate VFs (i.e., bilateral presentations). Participants vocally named the color of the colored strip as quickly and accurately as possible. For unilateral conditions, David found overall faster response times for the RVF, but he did not find a significant VF X Condition (Congruent/Incongruent stimuli) interaction. Thus, there was no hemispheric difference for the SE. Faster response times for RVF stimuli may be due to the requirement of verbal responses which are controlled and executed in the LH. In the bilateral condition he found a smaller interference effect than in unilateral presentations. In the bilateral
condition he did not find the VF X Condition interaction indicating that when the word was presented to the RVF and the color strip to the LVF, participants did not respond significantly different than for the reversed presentation (i.e., word in the LVF and color strip in the RVF) for congruent as well as for incongruent stimuli. The findings from bilateral presentations, which by their nature presupposes interhemispheric interactions, indicate that the transfer of information across the corpus callosum decreases the SE.

A final study that failed to find hemispheric asymmetries in Stroop performance was conducted by Bertke and Brown (1996). Vertical nonintegrated Stroop stimuli were either presented both to a single VF (i.e., unilateral presentations) or each component was presented to a separate VF (bilateral presentations). Participants vocally reported the color of the patch. Bertke and Brown found a significant SE. While they did not find a significant effect of position (i.e., unilateral vs. bilateral presentations), they did find a significant interaction between condition and position, indicating that the bilateral Stroop stimuli showed less SE as compared to unilateral Stroop stimuli. This finding is in accordance with David's findings (1992) and may indicate that when both hemispheres are involved in the processing of Stroop stimuli, the SE is reduced. In other words, obligatory involvement of the corpus callosum in processing spatially separated Stroop stimuli acts as partial barrier for the SE.

Studies Supporting Hemispheric Asymmetry

Soon after Dyer's study (described in previous section), Schmit and Davis published the first partial replication in 1974. Schmit and Davis hypothesized that the LH would show a greater interference effect than the RH because of the LH's specialization
for verbal processing. Each subject in the study was required to respond to unilateral presentations of integrated Stroop stimuli by manually indicating the color of the ink and the color word in separate sessions. Schmit and Davis found that the LH takes longer than the RH to process ink colors for incongruent Stroop stimuli (709 msec for the LH and 674 msec for RH). Their findings support the hypothesis that the LH is more prone to the interference effect. They not only found the interference effect present in the LH but also found it to be present to a lesser degree in the RH (interference in the LH was 74 msec and in the RH it was only 40 msec).

The following studies: Tsao, Feustel, and Soseos (1979); Guidard (1981); Hugdahl and Franzon (1985); Franzon and Hugdahl (1986, 1987); Weekes and Zaidel (1996) corroborated Schmit and Davis's (1974) findings that there is greater interference in the LH in the processing of integrated and nonintegrated lateralized Stroop stimuli. These studies will now be presented in turn (see Table 2).

Tsao et al. (1979) used integrated Stroop stimuli projected to each VF. Participants were required to verbally indicate the color of the stimulus as fast and as accurately as possible. Tsao et al. found an interaction between VF and Condition for error rate but not for response latencies: participants made significantly more errors in reporting colors in the RVF than in the LVF.

Testing a laterality output paradigm, Guidard (1981) used only foveally presented incongruent Stroop stimuli to which the participants responded using either the right or left hand to indicate the color or the word dimension of stimuli on separate sessions. He found a significant interaction between the hand used and the processing mode (e.g.,
color processing vs. word processing). The right hand was significantly faster for word processing than for color processing. There were no significant differences in the processing mode for the left hand. Guidard concluded that the asymmetry of motor performance depended on the processing mode. In other words, motor performance asymmetry indicates hemispheric asymmetry. Unfortunately, Guidard did not use the congruent Stroop stimuli as a control condition and therefore it is not possible to draw conclusions about the SE in motor performance asymmetry.

A series of studies using integrated and nonintegrated lateralized Stroop stimuli were conducted by Hugdahl and Franzon (1985) and Franzon and Hugdahl (1986, 1987). In the first study, Hugdahl and Franzon (1985) examined hemispheric asymmetries by using integrated lateralized Stroop stimuli with dextral and sinistral male and female participants. Sinistral participants were selected using a verbal dichotic listening task, while the dextrals were selected according to self-reported right handedness. All sinistral participants demonstrated a left ear advantage indicating a strong possibility that their RH was dominant for verbal processing. Hugdahl and Franzon hypothesized that there would be a reversed pattern of responding between the dextral and sinistral groups. Their hypothesis was based on the assumption that since these selected sinistrals are likely to have RH language specialization, they will demonstrate a greater susceptibility to interference for Stroop stimuli presented in the LVF. Participants were asked to verbally indicate, as quickly and accurately as possible, the color of lateralized, horizontally presented integrated Stroop stimuli. The dextral group displayed a statistically significant greater number of errors in the RVF than in the LVF when responding to incongruent
Table 1.2

**List of studies using lateralized (unilateral and bilateral) classical Stroop stimuli that found hemispheric asymmetries**

<table>
<thead>
<tr>
<th>Study</th>
<th>Uni/Bil</th>
<th>Ver/Hor</th>
<th>Man/Voc</th>
<th>M/F</th>
<th>DV</th>
<th>Conditions exhibiting asymmetries in the SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schmidt &amp; Davis, 1974</td>
<td>Uni</td>
<td>?</td>
<td>Man</td>
<td>M</td>
<td>RT</td>
<td>RT</td>
</tr>
<tr>
<td>Tsao, Feustel, &amp; Soesos, 1979</td>
<td>Uni</td>
<td>Ver</td>
<td>Voc</td>
<td>?</td>
<td>RT, Ac</td>
<td>Ac</td>
</tr>
<tr>
<td>Guidard, 1981</td>
<td>Foveal</td>
<td>Hor</td>
<td>Man</td>
<td>M, F</td>
<td>RT, Ac</td>
<td>Ac, output asymmetries</td>
</tr>
<tr>
<td>Hugdahl &amp; Franzon, 1985 (Exp 1)</td>
<td>Uni</td>
<td>Hor</td>
<td>Voc</td>
<td>M (Dex)</td>
<td>RT, Ac</td>
<td>Ac</td>
</tr>
<tr>
<td>Hugdahl &amp; Franzon, 1985 (Exp 2)</td>
<td>Uni</td>
<td>Hor</td>
<td>Voc</td>
<td>M (Sin)</td>
<td>RT, Ac</td>
<td>Ac, reversed pattern</td>
</tr>
<tr>
<td>Hugdahl &amp; Franzon, 1986</td>
<td>Uni</td>
<td>Ver</td>
<td>Voc</td>
<td>M, F</td>
<td>RT, Ac</td>
<td>RT, Ac, dex males only</td>
</tr>
<tr>
<td>Hugdahl &amp; Franzon, 1987</td>
<td>Uni</td>
<td>Ver</td>
<td>Voc</td>
<td>M</td>
<td>RT, Ac</td>
<td>RT, Ac, instruction depend</td>
</tr>
<tr>
<td>Long &amp; Lyman, 1987</td>
<td>Uni</td>
<td>Hor</td>
<td>Voc</td>
<td>M</td>
<td>RT</td>
<td>RT, reversed SE</td>
</tr>
<tr>
<td>Zaidel &amp; Weekes, 1996</td>
<td>Uni</td>
<td>Ver</td>
<td>Man/Voc</td>
<td>M, F</td>
<td>RT, Ac</td>
<td>Males only</td>
</tr>
<tr>
<td>Weekes &amp; Zaidel, 1996</td>
<td>Uni/Bil</td>
<td>Ver</td>
<td>Man/Voc</td>
<td>M, F</td>
<td>RT, AC</td>
<td>Males, low estrogen female</td>
</tr>
</tbody>
</table>

? = no information available
stimuli, replicating the Tsao et al. (1979) findings. However, for the sinistrals, the VF asymmetry \( (p < .10) \), considered by the researchers to be of borderline significance, was reversed: the sinistrals demonstrated more errors when the incongruent stimuli were presented in the LVF. For response time, there were no differences between the dextrals and sinistrals. The reversed performance pattern for the sinistrals was considered by Hugdahl and Franzon to be additional evidence for hemispheric asymmetries of the lateralized Stroop stimuli. As hypothesized, the hemisphere which is dominant for the verbal processing will demonstrate a greater susceptibility for the Stroop interference effect. Hugdahl and Franzon's findings provided additional evidence for hemispheric asymmetries for lateralized Stroop stimuli, particularly because of their careful selection of sinistral participants using the dichotic listening task.

In Franzon and Hugdahl's (1986) replication study, lateralized, vertically-oriented stimuli were presented to dextral and sinistral participants. The outcomes of this study replicated their previous findings using horizontally displayed stimuli. They concluded that the mode of stimulus display - horizontal versus vertical - does not play an important role in the outcome of the SE. They confirmed the findings from their previous study that dextral males have a greater error rate when the Stroop stimuli are projected to the LH. In this study, however, Franzon and Hugdahl found the same pattern for response latencies. Similar response patterns (i.e., more errors and longer latencies for incongruent stimuli in the RVF) for dextral females were not found. Franzon and Hugdahl failed to replicate the findings for sinistrals (i.e., more errors
when the incongruent stimuli are presented in the LVF than in the RVF) which they explained was caused by using unscreened sinistral subjects (e.g., the sinistrals were not selected by a verbal dichotic listening task).

Using the same procedures as in the previous studies, Franzon and Hugdahl (1987) examined hemispheric asymmetries in relation to speed/accuracy tradeoff by manipulating the task instructions given to right-handed male participants. Half of the participants were instructed to complete the Stroop task as quickly as possible, the other half was instructed to complete the Stroop task as accurately as possible. Results indicated that speed versus accuracy manipulations interfered with hemispheric asymmetry for the SE. When participants were instructed to be accurate, they had greater RTs for the incongruent stimuli presented in the RVF than for those presented in the LVF, but no differences were found for response accuracy. When participants were instructed to be fast, they made more errors for the RVF stimuli projections than for the LVF projections, but no differences were found for RTs (i.e., the hemisphere that exhibited the greatest SE depended on the dependent measure and whether accuracy or speed were emphasized). Based on these findings, Franzon and Hugdahl (1987) suggested that the lack of consistent hemispheric asymmetry findings in other studies may, in fact, be due to the instructional sets and/or the type of dependent measures used (e.g., response time vs. error rate).

The most recent study using lateralized Stroop stimuli to examine hemispheric asymmetries/hemispheric cooperation was published by Weekes and Zaidel (1996). They conducted a series of studies using the Stroop task to investigate: the stage of
information processing in which the SE occurs, hemispheric asymmetries, and individual differences. To achieve these objectives, Weekes and Zaidel manipulated the response mode (e.g., vocal vs. manual), the Stroop stimuli (e.g., integrated vs. nonintegrated stimuli), and VF (e.g., unilateral vs. bilateral). Across all of the manipulations, they found the SE. However, with the manual responses, they found the magnitude of the SE diminished.

Although Weekes and Zaidel investigated several factors in their study, for purposes of the current research, only the portion of the study focusing on the lateralized paradigm will be summarized. Using vertically presented lateralized integrated Stroop stimuli, Weekes and Zaidel found an overall main effect of VF, in which response times were longer for the RVF than for the LVF. Analyzing only manual responses, Weekes and Zaidel found hemispheric asymmetries only for males. The LH showed greater SE (i.e., longer RTs) than the RH. From these results Weekes and Zaidel concluded that the LH is more sensitive to the SE than the RH, especially for males.

In the next series of experiments, Weekes and Zaidel used nonintegrated Stroop stimuli (i.e., color word and color patch) presented to the same VF (i.e., unilateral presentations) or each component was presented to a separate VF (i.e., bilateral presentations). Weekes and Zaidel found a significant main effect for bilateral presentations: trials in which a word appeared in the LVF were responded to faster than trials in which a word appeared in the RVF. They also found a statistically significant interaction between VF and Condition (congruent/incongruent) for males but
not for females. Males responded more slowly when the word was presented in the RVF, regardless of the location of the color patch presentation (e.g., color patch presented either in the RVF or LVF). Female performance varied with their menstrual cycle: hemispheric asymmetries were found for low estrogen females (i.e., females between the 3rd and 5th day of menses) but not for high estrogen females (i.e., females between the 7th and 10th day before menses).

In summary, Weekes and Zaidel found that unilateral stimuli produced a greater SE than bilateral stimuli, that the SE was more robust for males than for females, and that hemispheric differences were present when incongruent stimuli were projected to the RVF. More specifically, the interaction between VF and Condition (Congruent/Incongruent stimuli) was present for the bilateral presentations when the word was projected to the RVF, regardless of the color patch presentation. The previously discussed findings were obtained for males and for low estrogen females only. Weekes and Zaidel concluded that there appears to be hemispheric asymmetries in the processing of the lateralized Stroop stimuli; the LH is more susceptible to the Stroop interference effect than the RH. Overall, these asymmetries are sensitive to the sex of participants (i.e., males demonstrated greater SE than females) and response mode (i.e., with vocal responses there were no sex differences).

There was only one study which found the reverse hemispheric asymmetries (i.e., greater SE in the RH) in performance of the lateralized Stroop stimuli. Namely, Long and Lyman (1987) manipulated the spatial and temporal proximity of the two dimensions of the Stroop stimuli and found a reversed hemispheric asymmetry.
Participants responded by vocally naming the color patch of the Stroop stimulus which was presented laterally, while the word (i.e., distractor) was presented foveally. The temporal dimension was manipulated by presenting the distractor prior to, at the same moment, or after the onset of the color patch target. A VF X Condition interaction resulted in which there were longer latencies for the incongruent stimuli in the LVF than in the RVF. The authors offered a callosal relay interpretation for their findings: the longer response time for the color component of the incongruent stimuli projected to the LVF resulted from the transfer time of the color code from the RH to the LH for the vocal response.

This review of studies demonstrating hemispheric asymmetries in the lateralized Stroop task indicates that hemispheric asymmetries are more pronounced for males than females when incongruent stimuli are presented in the RVF. The greater SE in the RVF than in the LVF is in accordance with both the relative speed of processing model and the automaticity model.

Hemispheric Asymmetries in Stroop Tasks: Conclusions

There appears to be mixed findings concerning hemispheric asymmetries in the performance of the Stroop task. The above reported studies are almost evenly split regarding the support or lack of support for hemispheric asymmetries for the SE. Looking at the experimental manipulations of the studies (see Table 1.1 and Table 1.2) there is no unambiguous indication as to which manipulations reliably and consistently produce hemispheric asymmetries (stimulus type, eccentricity of stimulus presentation, response mode, mode of processing - naming versus matching). However, Franzon
and Hugdahl (1986, 1987) and Weekes and Zaidel (1996) demonstrated that the SE in lateralized presentation of Stroop stimuli is more prominent among males than females. Franzon and Hugdahl (1986, 1987) additionally found that task instructions can affect hemispheric asymmetries.

Nevertheless, the studies indicating hemispheric asymmetries for the SE are highly consistent in that the LH is more sensitive to the SE than the RH, as indicated by longer response latencies and/or more errors for RVF stimulus presentations. There is only one study indicating a reversed SE (Long & Lyman, 1987); the reversed laterality effect in this study is not of particular surprise, since the words were presented foveally and participants responded vocally.

In the most comprehensive review of the SE, MacLeod (1991) concluded that "the left hemisphere generally shows more interference than the right" (p. 186). My review indicates that MacLeod's statement should be revised. Therefore, MacLeod's criteria for "the major empirical results that must be explained by any successful account of Stroop effect" (p. 203, criteria 17) is not valid for hemispheric asymmetry since there is approximately a 50% or less chance that the researcher will obtain the hemispheric asymmetry although there will almost always be a SE present for each hemisphere.

There are several possible explanations for the lack of a hemispheric asymmetry for the SE. First, and perhaps the most obvious, may be that neither the speed of processing model nor the automatic processing model are fully able to explain differences in hemispheric patterns of responding. According to these two models,
there should always be a stronger SE when the Stroop stimuli are presented to the LH than to the RH because of LH specialization and superiority for word processing which should interfere with color naming. But the previous explanation may be ill conceived in light of a second explanation: the two hemispheres sometimes function independently and sometimes as a coupled system. When the two hemispheres function independently, a hemispheric asymmetry can be obtained. On the other hand, when the two hemispheres function as a unified system, hemispheric asymmetry should not be evident. This idea is indirectly supported by David's (1992), Bertke and Brown's (1996), and Weekes and Zaidel's (1996), findings that the overall functioning was faster for bilateral presentations than for unilateral presentations. According to Banich's (1995) interpretation of hemispheric interactions, the comparison of unilateral with bilateral presentations is the most appropriate test of interhemispheric processing. Unilateral trials serve as a baseline for the bilateral trials. Improvement of performance with bilateral presentations versus unilateral presentations may be an indicator that the Stroop stimuli were better responded to when the two hemispheres functioned as a coupled or unified system. Better performance of bilaterally presented Stroop stimuli may be attributed to more efficient sharing of the processing resources between the two hemispheres.

The main question in the lateralized Stroop paradigm, therefore, is when and why do the two hemispheres function independently or unified. Is there a way to manipulate the presentation of Stroop stimuli so that a reliable and consistent hemispheric asymmetries can be produced? The answer may be yes if experimental
parameters are carefully manipulated: either integrated or nonintegrated stimuli with manual responses with male participants! By consistent production of hemispheric asymmetries through the use of selective experimental manipulations, we can gain more insight into the functional relationship between the two hemispheres at least for right handed males.

Lateralized Stroop analog tasks

A new Stroop analog task will be used in the current study, using nonintegrated stimuli composed of the photographs of human faces (i.e., male, female, and baby face) and corresponding words (i.e., man, woman, baby). No known study has been conducted using this Stroop analog. Studies pertaining to lateralized picture-word and face stimuli will be briefly reviewed.

Line Drawing Stroop Analogs - Hemispheric Asymmetries

Several studies (Lupker & Sanders, 1982; Toma & Tsao, 1985; Wuillemin, Krane, & Richardson, 1982) provide evidence that lateralized picture-word Stroop analogs may be appropriate for the investigation of hemispheric asymmetries.

Lupker and Sanders (1982) found that processing of lateralized picture-word Stroop analogs (i.e., pictures from children's coloring books superimposed on words from the same or unrelated semantic category, versus pictures alone) produced a greater SE in the LH when there were semantic and phonetic similarities between the line-drawings and the words. However, the authors also found an interference effect in the RH that they believed to be of a perceptual nature. Lupker and Sanders contended
that processing of the picture-word stimuli may be slower in comparison to a picture alone condition because of early perceptual interferences in the RH.

Wuillemin, Krane, and Richardson (1982) presented unilateral and bilateral picture-word Stroop-like stimuli to participants in which they were to name the picture. Wuillemin et al. did not find hemispheric asymmetries but they found that unilateral presentations produced greater interference than bilateral presentations.

Toma and Tsao (1985), replicating the Tsao et al. (1979) study that used a lateralized presentation of classical Stroop stimuli, presented line drawings of common objects with embedded four letter words or non-words in the LVF and the RVF. Toma and Tsao's findings revealed hemispheric asymmetries such that the LH made more errors than the RH in the naming picture drawings. No differences between hemispheres were found in presentations where the non-words were embedded within the line drawings.

**Face Tasks - Hemispheric Asymmetries**

Hemispheric asymmetry studies using lateralized face photographs have produced growing evidence and agreement among researchers that the RH is superior for face-gender discrimination/categorization tasks, and, to a certain degree for face recognition tasks (Hellige, 1993; Hellige, Corwin, & Johnson, 1984; Keenan, Whitman, & Pepe, 1989; Proudfoot, 1982; Rhodes, 1985, 1993; Sergent, 1985; Sergent, Ohta, & Macdonald, 1992; Schweinberger, & Sommer, 1991; Schweinberger, Sommer, & Stiller, 1994).
Sergent, Ohta, and Macdonald (1992) conducted a series of experiments using lateralized face stimuli to investigate hemispheric asymmetries and brain structures involved in face processing. In one experiment, Sergent et al. laterally presented typical male and female faces for a gender discrimination task. Response times were faster for LVF presentations than for RVF presentations suggesting RH superiority.

In order to find hemispheric asymmetries with lateralized face processing tasks (i.e., LVF advantage for face processing), Hellige (1994) suggests that experimenters use a small set of unfamiliar, highly discriminable and/or perceptually degraded faces in a simple categorization task, such as a gender classification task.

In a positron emission tomography (PET) study, Sergent et al. (1992) demonstrated that for face-gender discrimination, the right hemispheric structures (i.e., right extrastriate cortex and right parahippocampal gyrus) were involved in the processing. Additional evidence of RH involvement in face processing comes from lesion studies and studies with prosopagnostic individuals (individuals who can not recognize known faces) (Damasio, Tranel, & Damasio, 1990). Difficulties in processing known faces are caused primarily by lesions in the right ventro-medial occipito-temporal region.

Levy et al. (1972) demonstrated that split brain patients are able to perform chimeric face recognition tasks regardless of which VF the face stimuli are presented, but they make faster responses to stimuli presented to the RH. This finding indicates that the face recognition task is a direct access task (i.e., each hemisphere can perform the task independently) with RH superiority. Lesion studies, studies with
prosopagnosics, and studies using lateralized experiments with normal individuals indicate that the RH is better than the LH in performing lateralized face tasks.

**Lateralized Stroop-like Tasks: Conclusions**

Predictions concerning hemispheric asymmetries for a Stroop-like task involving face processing are difficult given the novelty of the newly proposed Stroop analog and the paucity of studies using similar Stroop-like analogs. However, the previously reviewed studies relating to the use of Stroop-like tasks with lateralized line drawings, and face processing tasks suggest that the proposed Stroop analog should produce hemispheric asymmetries with greater interference effects in the LVF than the RVF for face classification tasks.

**Neuroanatomical and Neurophysiological Bases for the Stroop Effect**

Although more than a thousand studies with the Stroop task have been published, a paucity of studies exist which explore the neuroanatomical and neurophysiological substrates associated with the SE. With recent developments in brain imaging technology, it might be expected that research using this technology would be conducted to investigate the underlying brain structures involved in the SE; however, such investigations have been minimal. To date there have been seven articles related to the EEG/ERP domain and two articles using Positron Emission Tomography (PET).

**Neuroanatomical Substrates of the Stroop Effect**

Even though the Stroop task is very simple, it has been widely accepted and used as a psychodiagnostic tool either as a measure of interference or selective
attention. In both cases, the Stroop test is considered sensitive to dysfunction caused by closed head injuries, and indicates subtle attentional deficits (Lezak, 1995). Studies with brain lesioned patients (Hoist & Vilkki, 1988; Perret, 1974) demonstrated the Stroop test to be susceptible to frontal lobe lesions. Therefore, the Stroop task implicates the involvement of frontal lobe structures in the performance of intact subjects.

The Stroop Effect in Acallosal and Split Brain Patients

Some of the latest attempts to identify neuroanatomical substrates associated with the SE have been with split brain patients and individuals with congenital absence of the corpus callosum (i.e., acallosals). Research with these populations may potentially increase our understanding concerning the transmission or non-transmission of information across the corpus callosum. Hemispheric interactions can be investigated by lateralized presentations of separate components of Stroop stimuli (color and word) to separate visual fields. In this manner, a single component of the Stroop stimulus will be sent to an individual hemisphere. With such presentations, the expectation is that patients without proper interhemispheric connections will exhibit a weaker SE or no SE. As previously discussed, the SE occurs when the faster processing component of the Stroop task (color word identification) interferes with the slower component (color ink identification). Since the corpus callosum in split brain patients and acallosal individuals is missing, there is limited communication between the two hemispheres, and hence the SE should be minimized.
David (1992) published the first study designed to explore whether interhemispheric interference/facilitation effects occur when the corpus callosum is lacking. He studied three acallosal patients, one lacked an anterior commissure. For the other two, David did not provide information regarding the presence or absence of the anterior commissure. Nonintegrated Stroop stimuli were presented either within each VF (unilateral condition) or the color word (written in a black font) and color patch were presented to separate VFs (bilateral condition). Even though two of the patients had additional neurological impairments (e.g., seizures, syndrome of Ito) and lower intellectual functioning, David found a drastic reduction of the SE in the acallosal individuals with the bilateral presentations, which was assumed attributable to the lack of connecting fibers between the two hemispheres. This finding would imply that in normal individuals, the SE for bilateral trials occurs as a result of interhemispheric transfer of semantic or color information. If a drastically reduced SE were to occur in acallosal individuals with bilateral presentations, then the logical inference would be that the observed SE in normal individuals with bilateral presentations results from successful interhemispheric transfer.

In a similar study, Zaidel (1995) presented unilateral and bilateral nonintegrated Stroop stimuli to two split brain patients with complete section of the forebrain commissure including the corpus callosum and the anterior commissure. The experiment was conducted twice using different response options: vocal color naming or a motor response in which the subject indicated the color by pressing one of three buttons that represented the color stimulus. The manual response version was
presented twice so that the split brain patients had a session with each hand. Zaidel predicted that split brain patients would be able to vocally name RVF but not the LVF color patches, and that the SE would occur only when both components of the Stroop stimulus appeared in the same VF. However, for the bilateral presentations, the SE was not expected since information processing of both components should not be integrated, and consequently, would not cause interference. Both patients NG and LB exhibited more consistent SE for LH than for RH for unilateral presentations. Surprisingly, LB also showed the SE when the colored patch occurred in the LVF and the color word occurred in the RVF for right hand responding (i.e., presumably there was subcortical transfer of information between the two hemispheres). Despite this unexpected finding, Zaidel concluded that in normals, the corpus callosum is involved in the SE for bilaterally presented Stroop stimuli.

Bertke and Brown (1996) presented vertical nonintegrated Stroop stimuli to one right handed and one left handed male patient with agenesis of the corpus callosum, but preserved anterior commissures. The acallosals vocally identified the color of the patch. Both acallosals showed a significant SE, which did not differ between unilateral and bilateral presentations. The authors’ conclusion was that the anterior commissure is involved in the transfer of semantic information, and consequently in the interhemispheric SE as well.

Research conclusions related to the SE with split brain and acallosal patients, at this point, should be carefully considered because of the high variability in Stroop task performance among these patients and because of the small sample size (n = 7). For
bilateral trials, however, patients without a corpus callosum and anterior commissure typically exhibit a reduced or absent SE [except patient LB, who has shown inconsistent bilateral performance across sessions (Zaidel, 1995)]. This suggests that the transfer of information between the hemispheres via the corpus callosum or anterior commissure is necessary for the bilateral SE. Overall, findings with split-brain patients and acallosal individuals suggest that the corpus callosum, along with other commissures, automatically transfers visual and/or semantic information involved in the production of the SE.

**Electrophysiological - Event-related potential (ERP) Evidence for the Stroop Effect**

**Introduction to ERP methodology.** While the EEG approach to examining electrophysiological functioning of the brain focuses on rhythmic oscillations (frequency) in voltage, the ERP approach focuses on temporal changes (time) of electrical activity in relation to sensory, motor, or cognitive events. In most cases, ERPs reflect processing and responding to stimuli (Coles, Gratton, & Fabiani, 1990; Kutas, 1988) in that the ERPs are segments of the EEG (i.e., epochs) that are time locked to some external event. ERPs are produced primarily by graded cortical extracellular postsynaptic potentials (Martin, 1991). Unfortunately, the potentials from other generators of electrical activity may be superimposed on the ERP of interest, thus making localization of ERP generators problematic, and in some cases, misleading. However, ERPs have an excellent temporal resolution and as such can provide detailed information about the temporal changes in brain functioning as they relate to cognitive processing.
After averaging over many time-locked EEG epochs, the overall ERP waveform is obtained with characteristic positive and negative deflections. These deflections are also called components and are designated as positive - P or negative - N according to their polarity. The number that follows the capital letter (P or N) indicates the approximate latency of the component in milliseconds (e.g., P300) or the sequence of the component (e.g., N2 indicates the second major negative component) (Picton, 1992). According to several authors (Coles, Gratton, & Fabiani, 1990; Altenmuller, 1993), ERP components can be divided into exogenous and endogenous subtypes. Exogenous ERP components are related and controlled by the physical properties of an external event, while endogenous ERP components reflect internal, "cognitive" processes.

The most frequently recognized and discussed exogenous ERP components are the N100/N1 and the N200/N2. The N1 component represents the first negative deflection peaking between 90 and 200 msec after stimulus onset. This component is related to the orienting response (Altenmuller, 1993) because it is primarily enhanced by novel stimuli. N1 amplitude decreases with repeated stimulus presentations (Altenmuller, 1993) suggesting habituation of the orienting response. According to Altenmuller (1993), the N2 exogenous component reflects three different types of stimulus processing: N2a or "mismatch negativity" indicates passive (preattentive) discrimination, N2b indicates active discrimination, and N2c indicates a categorization process. The N2c component can also be classified as an endogenous component since categorization can be considered an internal or cognitive process.
The two major endogenous components are P300/P3 and N400/N4. The P3, also called "late positive complex" (Altenmüller, 1993), reflects the broad positive deflection 200 - 800 msec after the onset of the stimulus. Two different types of P3 components have been found: the P3a component, which appears earlier and is distributed more over the frontal scalp, and the P3b, which appears later and is distributed more over parietal sites. The P3a is observed after the N2b in response to novel stimuli (Altenmüller, 1993; Picton, 1992) and reflects the involuntary capture of attention by salient events (Coles & Rugg, 1995). According to some researchers (Coles, Smid, Scheffers, & Otten, 1995; Kutas & Van Petten, 1994), the P3b reflects stimulus evaluation as well as decision making. Other authors (Altenmüller, 1993; Polich, 1993) associate the P3 to memory updating. Coles and Rugg (1995) maintained that the P3b occurs after the completion of the processes necessary for stimulus evaluation and before the processes involved in response selection and execution. It appears that there is some agreement among several authors (Altenmüller, 1993; Coles & Rugg, 1995; Picton, 1992) that the P3 amplitude is directly related to stimulus relevance and task difficulty. P3 latency, on the other hand, can be used as a measure for the timing of the stimulus evaluation and stimulus categorization (Altenmüller, 1993; Coles, Smid, Scheffers, & Otten, 1995).

The N4 endogenous component reflects the negative deflection at around 400 msec in word processing and it typically precedes the P300 component. It was discovered by Kutas and Hillyard (1984), and occurs when the participants read a sentence with an anomalous word at the end (e.g., "He takes cream and sugar in his
SHOE.") but not when they read a sentence that has an expected ending (e.g., “He takes cream and sugar in his COFFEE.”). Therefore, the N400 is elicited by an incongruity in a sentence. However, some researchers (Coles, Smid, Scheffers, & Otten, 1995; Kutas & Van Petten, 1994) have reported that the N400 can be elicited by tasks involving grammatical processing, in addition to semantic processing. The variations in N4 amplitudes are considered as indications of semantic priming (Kutas & Van Petten, 1994). The proposed experiments will address whether the N400 is similarly influenced by congruent versus incongruent Stroop conditions.

Review of Stroop ERP Studies

Scott, Hoffman, and Bickford (1967) conducted the first ERP study using Stroop stimuli. The focus of this study was on an early parietal-occipital potential called the lambda wave. This wave is characterized by an initial negative component followed by a positive deflection at approximately 100 msec. According to Scott et al., the lambda waveform is typically obtained when subjects scan a patterned visual field. In this study the traditional Stroop test was used consisting of 3 cards, each with 60 congruent, incongruent or neutral stimuli; participants were required to name the colors. An additional card with 60 black squares was used; the participant was required to count the number of blocks on the card. ERPs were measured over the parietal and occipital lobes (presumably Pz and Oz). The marking of the beginning of each ERP was triggered by an eye movement from one stimulus to another stimulus. The results indicated a greater lambda amplitude for the incongruent stimuli as compared to the congruent, neutral, or black block stimuli. In other words, the
cognitive processing of the incongruent Stroop stimuli requires higher mental activity, resulting in the larger lambda amplitude than for congruent or control stimuli.

Further research efforts using ERP and the Stroop task focused on resolving the ongoing debate concerning the locus of the SE. A primary question relates to whether interference occurs during the stimulus processing stage or whether it occurs during the response retrieval and/or response selection stage. Duncan-Johnson and Kopell (1981), administered the classic Stroop test and concurrently recorded response times and ERPs. They assumed that the P3 is an indicator of the process of stimulus evaluation and is independent of response time, since response time depends not only on stimulus evaluation but also on response selection and execution. Duncan-Johnson and Kopell reasoned that if response latency and P3 latency are indeed dissociable, then the P3 should occur at approximately the same time for incongruent, congruent, and neutral stimuli. This would indicate that the interference occurs after stimulus evaluation because for response times there is an increase of approximately 50 - 100 ms for the incongruent stimuli as compared to congruent or neutral stimuli.

Duncan-Johnson and Kopell (1981) presented the classic Stroop stimuli foveally, and in one session subjects vocally named the ink color, while in a separate session they named the word. ERPs were recorded at frontal (Fz), central (Cz), and parietal (Pz) midline sites. The Stroop stimuli produced a clear P3 in both the color naming and word reading conditions. The P3 peak amplitude latencies were found to be the same for all three types of stimuli: incongruent, congruent and neutral stimuli. However, a significant difference between reaction times was found, with the longest
response times being for incongruent stimuli. Based upon these findings, Duncan-Johnson and Kopell concluded that the Stroop interference effect occurs subsequent to stimulus evaluation.

To control for the possible confounding between color naming and word reading in P3 component production, Duncan-Johnson and Kopell conducted an additional experiment in which they manipulated the discriminability of the color of the ink by adding two more colors to the word blue and red: reddish purple and bluish purple. The decrease in color discriminability resulted in a prolonged response time as well as a longer P3 latency regardless of the compatibility of conditions. For Duncan-Johnson and Kopell, the correspondence of increased P3 latency with longer response times, is additional evidence that the P3 is elicited after the processing of color information (i.e., stimulus evaluation). Duncan-Johnson and Kopell concluded that the Stroop interference occurs in the response stage of information processing and is likely to be caused by response competition.

Based on the same premise, that the P3 is an indicator of stimulus processing and is independent of response retrieval, Czigler and Csibra (1991) conducted a study using a non-classical lexical Stroop task. The stimuli were foveally presented four-letter strings, half were words and half were non-words. Directly below each letter in the string was a number ranging from one to four that indicated the order in which the letters were to be rearranged; numbers below the letters were not necessarily sequential. Participants were required to manually indicate if the reordered strings of letters were words or non-words in the Hungarian language. Czigler and Csibra
hypothesized that when the four letter strings were actual words, and when the rearranged order of letters also constituted a word, then this condition would facilitate response times and would parallel the congruent Stroop condition (e.g., LIFE cued as 3214 gives FILE). Conversely, when the initial letter string was a word stimulus that resulted in a non-word following reordering, there would be an interference effect (i.e., incongruent stimulus).

Behavioral results indicated a Stroop-like interference effect in that subjects showed a significantly longer response times for the word stimulus cued as a non-word (e.g. stimulus "TIDE" cued 3214 gives a letter combination "DITE" which is non-word) than to the non-word cued as a non-word (e.g. stimulus "NARE" cued 4213 gives a letter combination "RAEN" which is a non-word). This effect was considered a SE because in lexical decision tasks the initial word stimulus interfered with the processing of the non-word stimulus.

From the ERP data, Czigler and Csibra obtained four components from the post-stimuli epochs: N1, P2, N2, and P3. Statistical analysis did not indicate any significant differences in amplitudes or latencies between the conditions, although there was a significant effect of electrode location. There was no correspondence between the latencies of any ERP components and response times. In the pre-response segment ERP, Czigler and Csibra identified a large positivity ranging from 700 to 300 ms prior to the overt responses, which had the largest amplitudes to the word cued non-word incompatible condition. Czigler and Csibra hypothesized that this late positivity component may reflect interference between the available irrelevant semantic code with
stimulus retrieval. They concluded that "the positive wave in the range of overt responding might be a very late member of the P3 family, and it can be related to the final matching between the representation of the stimulus and an item in the lexical memory." (Czigler and Csibra, 1991, p. 291).

**Attention Studies Using the Stroop Task**

Several ERP studies have been reported utilizing the Stroop test as a measure of attention, particularly selective attention. In these studies, either of the Stroop stimuli (i.e., congruent or incongruent stimuli) or single component of the Stroop stimuli (i.e., word or ink color), may be use as the targets to which the participant must attend. The first published study of this type was done by Johnson and Venables in 1982. The focus of that study was the first positive component, P85, and its responsiveness to the manipulation of Stroop stimuli. Johnson and Venables hypothesized that the early P85 ERP component would reflect the "stimulus set", that is, the specific physical characteristics of the stimulus. Using the Stroop test, they predicted that the attended feature of the stimulus, either the color or the word, would enhance the early P85 component.

In order to test their hypothesis, Johnson and Venables developed five types of Stroop stimuli: incongruent stimuli (color name and word ink differed), color names in black ink, non-specific word in black ink (e.g., HOUR in black ink), specific color stimuli [the letters of the congruent stimuli scrambled into nonsense words, (e.g. "ERD" in red ink)], and non-specific color stimuli (the letters of words pink, orange, brown, and mauve scrambled into nonsense words). The incongruent stimuli were
assigned as targets and the rest of the stimuli were assigned as probes which should be ignored by the subjects. The task was to name the color for one half of the trials and to read the word for the other half of the trials. The stimuli were foveally presented and recordings were only made from an occipital site (Oz).

Johnson and Venables found that the effects of different stimuli were highly specific: P85 amplitude was enhanced by the color feature of the incongruent stimuli when the participant responded to the color. The P85 was enhanced in a similar way by the word feature, but only when the participant was required to attend to the reading of the word and ignore the color of the stimulus. Non-specific stimuli did not show any differential effect for color naming or word reading. Johnson and Venables did not find any significant differences for P85 latencies. They concluded that their results did not support the late selection filter theory of attention, but, instead, provided evidence that attention has a specific effect on the early stages of information processing.

Aine and Harter (1984) looked for interhemispheric and intrahemispheric differences of scalp ERPs associated with Stroop tasks measuring selective attention. Aine and Harter used the stimuli "red" and "blue" written in red and blue colors. Stimuli were presented foveally, and participants were required to lift their index finger from a microswitch whenever a target appeared. Either a color or a word was assigned as a target. Aine and Harter created four conditions regarding the conjunction of the colors and words with regard to the target: (a) a congruent condition in which the word and color matched the target, (b) a condition in which only the color matched the target and the word was different, (c) a condition in which only the word matched
the target and the color was different, and (d) a condition in which neither the word nor
the stimulus matched the target. ERPs were recorded from left and right central (C3
and C4) and occipital (O1 and O2) sites.

The most prominent feature was a negative component peaking between 225 and
325 ms, with the peak being greater for the nontarget stimuli (absent feature of the
stimulus). This component was noted to be more pronounced over the LH than the
RH. Upon further analysis of the differences between the four conditions, Aine and
Harter concluded that over the occipital region: (a) color processing started at between
183 to 273 ms after the onset of the stimulus in both hemispheres, indicated by
increased negativity, and (b) word processing began approximately 273 ms after the
onset of the stimulus with greater amplitudes over the LH. According to Aine and
Harter, the late activity over the occipital region most likely originated from the
parietal association areas.

Over the central region, a similar pattern was found except that: (a) the negative
processing occurred later than for the occipital region, (b) word processing was
noticeable only over the LH, and (c) only the LH showed an interaction between color
and word processing. Based on their findings, Aine and Harter concluded that the LH
is primarily involved in the processing of the features of the target stimuli, more so
when the target was a word than a color.

A major problem with this study was that the participants were required to
respond within 458 msec, otherwise the response was discarded. Thus, the response
had to be executed very fast and, as such, the task imposed excessive stress and
demands upon the subjects. The stress may have interfered with their performance on the test.

Miller, Kavcic, and Leslie (1996), using the classic Stroop stimuli, designed a study to detect ERP differences between eight to ten year old boys with Attention Deficit Hyperactivity Disorders (ADHD) and normal control boys, and to detect the effects of Methylphenidate on ADHD boys. Miller et al. foveally presented congruent Stroop stimuli as the targets and incongruent Stroop stimuli as the non-targets. ERPs were recorded from 19 sites.

For all participants, ERP analysis yielded several components which were divided into anterior and posterior components: the anterior components included N1 and P2, while the posterior components included P1, N2, P3a, and P3b. Miller et al. interpreted the topographical distribution of the components according to the Posner and Petersen's (1990) attentional model. According to this model, humans possess a highly interactional attention system, similar to the perceptual or motor systems. The interactional attention system is widely distributed across the brain and implicates certain brain structures in different attentional processes such as alerting, orienting, vigilance and selective attention. Miller et al. concluded that the anterior components, N1 and P2, correspond to selective attentional processes, while the early posterior components, P1 and N2, reflect stimulus recognition and orienting.

In summary, ERP studies disclose a variety of ERP components involved in the processing of the Stroop stimuli. Some studies, using the Stroop stimuli to investigate the effects of selective attention (Aine & Harter, 1984; Johnson & Venables, 1982),
focused on early/exogenous components and provided evidence that selective attention is associated with early ERP components. On the other hand, Miller et al. (1996) showed that the processing of the Stroop stimuli in target/nontarget fashion produced early exogenous ERP components as well as late endogenous components, distributed over all the scalp. Other studies (Duncan-Johnson & Copell, 1981; Czigler & Csibra, 1991) focused on late ERP component (e.g., P3) and provide additional evidence that the SE occurs after stimulus evaluation.

**PET Studies Related to the Stroop Effect**

Technological developments in the last decade have improved brain imaging technologies dramatically, particularly positron emission tomography (PET), which measures the regional cerebral blood flow in the living brain. A common PET approach to studying brain functioning is based on the comparison of two different cognitive processes (e.g., processing of the congruent and incongruent stimuli). The difference in neuronal activity of the two cognitive processes is then associated with localization of the cognitive processes of interest.

Pardo, Pardo, Janer, and Raichle (1990) conducted a study employing the PET subtraction approach using Stroop stimuli. They acquired 40 sec PET scans from eight subjects who were foveally presented Stroop stimuli in a fixed order (e.g. a congruent stimuli session followed by an incongruent stimuli session) and with an interstimulus interval of 350 ms. The participant’s task was to verbally name the color of the stimulus as quickly as possible.
Unsubtracted results indicated increased neuronal activity in bilateral prestriate areas, left premotor, supplementary motor and left postcentral areas, the left putamen, the inferior anterior cingulate cortex, and the right temporal-parietal area. The bilateral extrastriate areas were found to be involved in visual information processing (word recognition), while the left premotor, the left supplementary motor, and the left postcentral areas were found to be involved in vocal output (word production). These neuronal responses indicate that the Stroop test requires an extensive neuronal network for appropriate performance. The only differences between congruent and incongruent condition were in the right temporal-parietal region and in the right anterior cingulate gyrus. For the difference in right temporal-parietal region, Pardo et al. offered no explanation. However, the authors concluded that the differences in the right anterior cingulate cortex may be attributable to the "selection process between competing processing alternatives on the basis of some preexisting internal, conscious plan" (p. 259).

Bench, Frith, Grasby, Friston, Paulescu, Frackowiak, and Dolan (1993) failed to replicate the Pardo et al. (1990) study in their first attempt. This was, in part, due to a departure from the original procedures of Pardo et al. (1990). Their procedures differed in that their interstimulus interval was 1 second, the congruent condition consisted of naming the colors of neutral words (e.g., the words front, back, top and down in different ink colors), and in that practice trials were given prior to PET scanning. With these differences in protocol, Bench et al. did not get the increased activation of the right anterior cingulate gyrus.
In their second attempt, Bench et al. more closely replicated the experimental procedures used by Pardo et al. (1990) by changing the interstimulus interval to 350 ms, by using classical congruent Stroop stimuli, and by not giving practice trials prior to the data acquisition. In each of their two experiments, Bench et al. used six subjects whose task was to verbally name the color of the stimulus as quickly as possible. For each subject the scan duration was 120 s. Results from the second experiment showed increased activation of the right anterior cingulate area but only when incongruent stimuli were contrasted with neutral stimuli. Bench et al. also observed increased activation of the posterior cingulate and the bilateral parietal association cortices when they contrasted the congruent condition with the neutral one. Bench et al. accounted for the disparity between their two studies as being due to the different rate of stimulus presentations and to possible practice effects in the first study. Bench et al. concluded that their second study supported the notion that the anterior cingulate gyrus is involved in response selection and that the activation of the parietal cortices is indicative of attentional manipulation. The Bench et al. (1993) study indicates that neural activation is highly sensitive to minor changes in experimental procedures, and is readily detected because of the high sensitivity of PET to changes in neuronal activation.

PET studies have furthered the understanding of the SE by implicating the involvement of anterior cingulate cortex in interference effects. The general role of the cingulate cortex is not yet well understood, but according to Roland (1993) the anterior cingulate gyrus is activated in selective attention tasks in which a target stimulus should be detected. Since PET does not reveal any differential activation of primary and
secondary visual association areas and/or "language" areas, which are involved in processing of the color and word stimuli features, it can be inferred that the right anterior cingulate cortex is selectively involved in the SE.

Proposed Experiments and Predictions

The proposed study examined behavioral (i.e., RTs and accuracy) and ERP data from participants performing lateraled Stroop and Stroop-like tasks. Four experiments were conducted: the first experiment focused on the performance of laterally presented nonintegrated classical Stroop stimuli, the second experiment addressed the issue of overlapping late endogenous components (P3 and N4) and response manipulation, the third and fourth experiments were conducted with a new Stroop analog task designed to produce greater interference effects in the RH.

Generally, it was expected that in all four experiments the previously mentioned ERP components, anterior N1 and P2, and posterior P1, N2, and P3 will be obtained. Furthermore, it was expected that an additional component, the N4, will also be present. The N4 component is an indicator of verbal processing; therefore, the N4 may be obtained with Stroop stimuli, even though the N4 has not yet been reported in any ERP Stroop study possibly because of P3 overlap.

Experiment 1

In Experiment 1, nonintegrated Stroop stimuli were horizontally presented either within each VF (unilateral presentations) or the word and color component appeared in separate VFs (bilateral presentations). It was expected that the SE would occur for both unilateral and the bilateral conditions. Furthermore, it was expected
that the SE would be greater for unilateral than for bilateral presentations. For the bilateral presentations, it was expected that the SE would be greater when the word is presented in the RVF as compared to word presentations to the LVF. It was also expected that the ERPs would correspond to the behavioral data: in the unilateral presentations, exogenous components would be greater over the hemisphere to which the stimuli were initially presented. Contrasting the two hemispheres, it was expected that there would be greater P3 amplitude over the LH than over the RH. Additionally, the N4 amplitude was expected to be greater for incongruent stimuli than for congruent stimuli.

Experiment 2

The focus of Experiment 2 was on the overlap of the late ERP components, the P3 and N4. Kutas (1994) warned ERP researchers of the possible existence of an overlap of the endogenous ERP components P3 and N4 because these components may occur in the same latency range. For example, Kutas maintained that in lexical decision tasks requiring an immediate response, the P3 and N4 components may overlap. According to Kutas, the overlap is primarily due to the P3 latency which varies with the complexity of the response decision. To examine Kutas's assertion, the lateralized Stroop task was conducted with a delayed matching response. The experimental procedures in Experiment 2 were the same as in Experiment 1 with respect to the stimulus presentations. Experiment 2 differed with regard to responding: a delayed matching response was required. Behaviorally, it was expected that there would be more errors and longer reaction times for incongruent than for congruent
trials. Comparison between the late P3 and N4 component amplitudes between Experiment 1 and Experiment 2, should indicate that the P3 amplitude would be greater in Experiment 1 than in Experiment 2. The amplitude of the N4 was expected to be greater in Experiment 2 than in Experiment 1.

Experiment 3

Experiment 3 utilized a face identification Stroop-like task that paralleled the procedures in Experiment 1; however, stimuli in this experiment consisted of digitized face photographs and face related words. Participants responded to faces and ignored the words. A greater SE was expected in the unilateral trials than in the bilateral trials. Furthermore, in the unilateral trials, there should be a greater SE in the RVF than in the LVF. For incongruent bilateral trials, it was expected that there would be a greater SE when the words are presented in the RVF than in the LVF. Consequently, there would be greater N4 amplitudes for incongruent trials presented in the RVF when compared to the presentations of incongruent trial to the LVF.

Experiment 4

Experiment 4 was conducted in order to investigate if there was an asymmetry for the face/word Stroop analog task by having participants respond to the word and ignore the face. In other words, in a classical Stroop task as well as in picture-word analogs, the word processing interferes with the color/picture identification, while the reverse is usually not the case. It was expected that the face processing would not interfere with word identification. Electrophysiologically, it was expected to find ERP components comparable to those obtained in Experiment 3. However, it was predicted
that in Experiment 4 there would not be differences in the P3 components for congruent and incongruent conditions, consistent with a lack of the SE in the behavioral data.
CHAPTER II

METHOD

Participants

A total of 88 male and female undergraduate students from the University of North Texas volunteered for this study (see Table 2.1) and received course credit. Participants were assessed for right-handedness with a modified Edinburgh Handedness Inventory (Oldfield, 1971), and for color vision with Ishihara Pseudo-isochromatic Color Plates (Ishihara, 1982). They were also screened for history of neurological problems. Only right-handed English speakers with no history of neurological problems, including episodes of unconsciousness, and with normal or corrected-to-normal vision as well as normal color vision participated in the study. Participants were informed prior to their participation in the experiment that all data would be kept confidential and that they may cease the experiment at any time.

Stimuli

For Experiments 1 and 2, nonintegrated Stroop stimuli were used and consisted of: (a) the color words BLUE, GREEN, and RED written in a white Helvetica, bold font (48 points), and (b) blue, green, and red rectangular strips. All stimuli were presented against a black background. In congruent conditions the spatially separated color word and color strip matched (e.g., the color word RED and a red colored strip),
Table 2.1

Number of males and females participants in four experiments

<table>
<thead>
<tr>
<th>Task</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateralized Stroop task</td>
<td>9</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>Lateralized Stroop task - delayed matching response</td>
<td>7</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Face/word Stroop analog - face target</td>
<td>11</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Face/word Stroop analog - word target</td>
<td>11</td>
<td>13</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td>38</td>
<td>50</td>
<td>88</td>
</tr>
</tbody>
</table>

while in incongruent conditions the color word and colored strip did not match (e.g., the word RED and a blue strip). For both, congruent and incongruent conditions, the word and the color strip appeared either both to the left or both to the right of the vertical meridian (i.e., unilateral presentations) or the word and the color strip appeared in opposite VFs (i.e., bilateral presentations).

In experiments 3 and 4, novel, nonintegrated Stroop analog stimuli were used, comprising of digitized colored photographs of a typical male, female, and baby face, and three words: MAN, WOMAN, and BABY. As in Experiment 1 and 2, a face and a word (e.g., a baby's face and the word BABY) were spatially separated either vertically (i.e., unilateral presentations) or horizontally (i.e., bilateral presentations). For congruent trials, the face and the word matched, while for incongruent trials they did not match.
In all four experiments, four visual locations were used for stimulus presentations. These positions were chosen to ensure equal spacing between within-visual field stimulus pairs and across-visual field stimuli. The four locations were as follows: 2 cm above and below the horizontal meridian and 2 cm to the left and right of the vertical meridian (i.e., at the four corners of a square). These locations ensured equal distance between neighboring stimuli (i.e., 4 cm). Thus, from a viewing distance of 100 cm, the inner edge of each stimulus was 2 degrees from the vertical meridian.

In all experiments stimuli appeared pseudo-randomly at two of four visual locations. Therefore, in each trial two of four locations were filled, one location with a color/face word, one with a colored strip/face.

For each presentation (i.e., unilateral and bilateral) the location of the word and the strip/face were counterbalanced such that half of the word presentations were below the horizontal meridian and half were above for unilateral presentations; half of the presentations were to the left and half to the right of the vertical meridian for bilateral presentations. The colored strip/face presentations appeared in the opposite location of the word in the same VF for unilateral presentations and in the opposite VF for bilateral presentations. Color words, face words, and color strips were displayed horizontally and subtended a visual angle of .75 degrees in height and 1.75 to 3 degrees in width; digitized face stimuli were presented in black ovals which subtended a visual angle of 2.5 (width) and 4 (height) degrees. A Macintosh Quadra computer was used to display all stimuli on a 15” VGA color monitor. The software program MacProbe (Hunt, 1994) was used for stimulus presentations, behavioral data collection, and for
sending pulse marker signals via a Lab NB board (Grass Instruments) to the A/D converter.

**Experimental Procedures**

**Experiment 1.** Experiment 1 was the lateraled Stroop task with presentation of nonintegrated Stroop stimuli. Each block consisted of 48 congruent and 48 incongruent stimuli presented bilaterally (i.e., BVF) and unilaterally (i.e., LVF and RVF) in equal proportions. Stimuli were pseudo-randomly presented within each of four blocks such that no more than two identical stimuli would appear twice in a row. For each trial, participants were required to identify the color of the colored strip by pressing one of three mouse buttons as quickly and accurately as possible. The response fingers associated with a particular color (i.e., index, middle, and ring finger) and hands used for responding (i.e., left and right hand) were counterbalanced across the participants.

**Experiment 2.** Stimuli presented in Experiment 2 were identical to those in experiment 1; the focus of this experiment was on response options. In Experiment 2 responses were delayed for 700 msec to investigate response effects on the SE, and to control for possible overlap and confounding of late ERP components. For each trial, 700 msec following the word-color stimulus presentation, a colored strip was presented above the fixation marker as a probe. The probe strip was identical to the previously displayed colored strip in half of the trials and different in the other half. Participants pressed one of two mouse buttons to indicate whether the displayed probe matched or differed from the Stroop color strip. The finger responses (index or middle) were counterbalanced across participants such that some participants used an index finger for
the response "match" and some participants used index finger for response "no-match". Participants changed the response hand after completion of the second block of trials. The presentation sequence was the same as in Experiment 1, except that 700 msec after stimulus presentation the probe appeared above the fixation marker.

**Experiment 3.** Experiment 3 incorporated the use of a lateralized Stroop-like task with Stroop stimuli analogs. Human faces (i.e., a male, female and baby face) and the words MAN, WOMAN, and BABY were used for congruent and incongruent stimuli. In all other aspects (i.e., stimulus presentations, presentation sequence, and response mode) Experiment 3 was identical to that of Experiment 1. The only difference was in the response decision: the participants were required to identify the face photograph as either male, female, or baby by pressing the appropriate mouse button as quickly and as accurately as possible.

**Experiment 4.** Experiment 4 was identical to Experiment 3 with respect to the stimuli set, stimulus presentations, presentation sequence, and response mode. The only difference was that in the Experiment 4 the participants were required to identify the face related word as either male, female, or baby as quickly and as accurately as possible, while ignoring the faces.

**EEG Recording Procedure**

Scalp EEG activity were recorded using an electrode cap (Electro-Cap International, Inc) designed according to International 10-20 System with 21 tin electrodes. Twenty electrodes (i.e., Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2) were referenced to the nose tip and grounded at
a midline location between Fpz and Fz. Additional electrodes were attached to the outer canthus of the left and right eye (bipolar derivation) for monitoring horizontal eye movements. The scalp EEG was amplified via a Brain Atlas III (Biologic Systems Incorporation) that is designed to measure electrical activity of the brain.

The EEG hardware was calibrated prior to data collection for each participant. A Lab Master DMA data acquisition board (Scientific Solution, Solon, OH) was used for analog-to-digital signal acquisition and controlled by a 486 personal computer. High and low pass filter settings were set at 30 Hz and 0.1 Hz, respectively. The cutoff frequencies for these filters were at 3 dB down with a roll off of 12 dB per octave at both sides. The gain was set at 15,000 times. Individual electrode impedances were maintained below 3 kOhms for each channel and balanced across all channels within a 2 kOhms range or less. In order to reduce the "hook-up" time, a Model 200 EEG electrode impedance meter (GDR Research, Lewisville, TX) was used. The software program ASYST (Keithley Metra Byte, Taunton, MS) was used to collect, average, and analyze the EEG data. An EEG sampling rate of 333 Hz (i.e., temporal resolution of 3 msec) with 12 bit resolution was used in order to provide a high resolution of the data. Epochs of approximately 1 sec duration were collected with the first 100 msec prior to target presentation used as a baseline. In Experiment 2, a second epoch was collected time-locked to the probe presentation, however this data was not analyzed.
Procedure

Following the signing of the consent form, the Ishihara Pseudo-isochromatic Color Plates were administered to the participant to screen for color blindness. Once normal color vision had been established, the participant was seated in a comfortable chair located in a sound attenuated room. While affixing the electrocap, the participant completed a questionnaire (see Appendix A) related to handedness, familial sinistrality and potential medical problems. Meanwhile, the experimenter explained the purpose of the experiment and outlined the experimental procedures. The participant was instructed to make key-press responses as quickly as possible without making errors. The participant was also instructed to fixate his/her eye gaze on the fixation point "+" at the center of the screen. In order to get optimal EEG data, the participant was asked to avoid unnecessary movements and eyeblinking.

Prior to each experiment, there was a 24 trial training block in which participants learned the appropriate response key sequence (e.g., the index finger indicated a blue colored strip in classical Stroop stimuli or woman’s face in face Stroop analogs). Participants then received 18 practice trials. An 80% response accuracy rate was required before beginning the experiment. Participants were repeatedly reminded to look at the central fixation point whenever it was presented.

Each trial began with a fixation point "+" appearing in the middle of the screen. Following an interval of 500 - 1500 msec, after the onset of the fixation point, the stimuli appeared 2 degrees to the left, right, or on both sides of the fixation point for 147 msec. In Experiment 2, however, 700 msec following a stimulus presentation
a probe was presented that was to be matched with a color strip of the Stroop stimulus. Participant had 2 seconds to respond, following which the fixation point disappeared from the screen and a high pitched (2000 Hz) or low pitched (200 Hz) tone was presented for 50 msec to indicate a correct or incorrect response, respectively. Reaction times (RTs) that were greater than 2 seconds were considered incorrect. Following a 1 second delay the next trial was initiated. Each trial lasted from 3500 to 4000 msec. At the completion of two blocks of 96 trials, there was an optional break.
CHAPTER III

RESULTS

General Analysis Procedures

Behavioral Data

For each experiment, RTs and accuracy scores were entered into a 2x2x2x2 mixed factorial ANOVA, with Sex (male, female) as a between-subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the Word (left visual field - LVF, right visual field - RVF), and Block (block 1, block 2) as within subjects factors. The second experiment had an added variable of Match (match, no match). For all four experiments, accuracies were very high (> 97%), and analyses of accuracy scores in all experiments did not reveal any significant effects and will not be reported. Only correct responses were used in the statistical analyses of RTs. The block variable was included in the ANOVA analyses in order to test for practice effects. All post-hoc analyses were carried out using the Tukey honestly significant difference (HSD) test and a family-wise Type I error rate of .05.

In addition to the analysis of all trials, two separate analyses were performed for unilateral and bilateral presentations. The reason for these two additional analyses was to tease apart Visual field effects since in the all trial analysis the Visual field variable was somewhat arbitrary (i.e., we could also have chosen Visual field of the color strip or face, rather than the word). Therefore, for unilateral trials the levels of the Visual field factor
were LVF and RVF, while for bilateral trials the levels were LVF-word/RVF-color and
LVF-color/RVF-word (or for Experiment 3 and Experiment 4 the bilateral trials were
LVF-word/RVF-face and LVF-face/RVF-word).

ERP Data

Off-line inspection and removal of all EEG epochs with artifacts (e.g., eye blinks
and eye movements) were completed prior to averaging. Due to the relatively greater
extent of artifacts and noise for 6 sites (Fp1, Fp2, F8, F7, T3, T4), analyses were
restricted to the following 14 sites: Fz, Cz, Pz, Oz, F3, F4, C3, C4, T5, T6, P3, P4, O1,
and O2. After averaging, the following six ERP components were identified across all
experiments:

1. Anterior N1 with peak amplitude latency approximately at 140 msec.
2. Posterior P1 with peak amplitude latency approximately at 120 msec.
3. Anterior P1 with peak amplitude latency approximately at 210 msec.
4. Posterior N1 with peak amplitude latency approximately at 180 msec.
5. N2 with peak amplitude latency approximately at 270 msec.
6. P3 with peak amplitude latency approximately at 380 msec.

Components labeled ‘anterior’ were analyzed for frontal and central sites (i.e., Fz,
Cz, F3, F4, C3, and C4). Components labeled ‘posterior’ were analyzed for temporal,
parietal, and occipital sites (i.e., Pz, Oz, T5, T6, P3, P4, O1, and O2). N2 and P3 were
examined for all 14 scalp sites. Due to the close proximity in peak latencies for the two
earliest components, these were analyzed as a two-component complex (i.e., anterior
N1/P1 complex and posterior P1/N1 complex). Contrary to our prediction, no N4 component was present in either Experiment 2 or in the other experiments.

The dependent measure for each ERP component or complex was the mean amplitude within a specific latency window as follows:

1. Anterior N1/P1 complex: 100 to 220 msec range;
2. Posterior P1/N1 complex: 90 to 220 msec range;
3. N2 component: 220 to 300 msec range;
4. P3 component: 300 to 500 msec range.

Mean amplitudes from each ERP component or complex were analyzed separately for vertex and lateral sites, in order that cerebral hemisphere could be treated as a variable for the latter. Unlike the behavioral analyses, block was not included as a variable due to the need for a sufficient number of trials in each ERP condition. The respective ANOVA designs follow:

1) Vertex sites: a 2x2x2x2x4 ANOVA with Sex (males, females) as a between subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (LVF, RVF), and Vertex site (Fz, Cz, Pz, and Oz) as within subject factors.

2) Lateral sites: a 2x2x2x2x5x2 ANOVA with Sex (males, females) as a between subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (LVF, RVF), Lateral site [frontal (F3/F4), central (C3/C4), temporal (T5/T6), parietal (P3/P4), and occipital (O1/O2)], and hemisphere (left sites, right sites) as within subject factors.
In addition to the analysis of all trials, separate analyses were performed for unilateral presentations and for bilateral presentations, as was the case for the behavioral data. Therefore, for unilateral trials, the levels of the Visual field factor were LVF and RVF, while for bilateral trials the levels were LVF-word/RVF-color and LVF-color/RVF-word (or for Experiment 3 and Experiment 4 the levels for bilateral trials were LVF-word/RVF-face and LVF-face/RVF-word).

For the posterior P1/N1 complex additional ANOVAs were performed using peak amplitudes for positive and negative components of the complex. This was performed since visual inspection indicated that the posterior sites exhibited the clearest unilateral visual field effects in terms of peak amplitudes and latencies shifts, that appear to reflect effects of interhemispheric transfer. An attempt was made to obtain the latencies for positive and negative peak amplitudes. Due to individual variability in waveform morphologies, the automated search gave unreliable peak latencies. Therefore, the peak latencies were obtained from averaged waveforms by manual detection of peak latencies. Consequently, peak latencies could not be statistically analyzed, and instead are presented at a descriptive level.

For the P3 component additional analyses were performed using peak amplitudes and latencies. The purpose of these analyses was to assess the validity of the mean amplitude analyses, as well as to check for differences in the time course of P3 component at different scalp sites and for different task conditions.

Geisser-Greenhouse adjustment for the degrees of freedom were used for the recording site factors due to the inherent violations of the repeated measures assumptions.
of sphericity (Greenhouse & Geisser, 1959). In an attempt to control for Type I error due
to multiple statistical tests, without unduly exacerbating the rate of Type II errors, a .01
level of significance was chosen to test each main effect and interaction. Where
appropriate, post-hoc analyses were conducted using Tukey HSD tests and a family-wise
Type I error rate of .05. Due to the complexity of high level interactions, only 4-way and
lower level interactions were analyzed. In addition, 4-way interactions involving the
variable Sex were not analyzed due to the relatively small sample size of males and
females.
EXPERIMENT 1- LATERALIZED STROOP TASK

Behavioral Data

Reaction times were entered into a 2x2x2x2 mixed factorial ANOVA, with Sex (male, female) as a between-subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the Word (left visual field - LVF, right visual field - RVF), and Block (block 1, block 2) as within subjects factors. All post-hoc analyses were carried out using the Tukey honestly significant difference (HSD) test.

The analysis of RTs revealed a significant main effect of Condition \([F(1,21) = 69.36, p < .0001]\) with faster RTs for congruent trials \((M = 644 \text{ msec})\) than for incongruent trials \((M = 680 \text{ msec})\). There was also a statistically significant main effect for Presentation \([F(1,21) = 9.49, p = .006]\), indicating that RTs for unilateral trials \((M = 658 \text{ msec})\) were faster than for bilateral trials \((M = 666 \text{ msec})\).

The ANOVA also revealed several significant interaction effects: Presentation and Visual field of the word \([F(1,21) = 12.90, p = .002]\), Sex and Block \([F(1,21) = 6.38, p = .02]\), Presentation and Block \([F(1,21) = 5.89, p = .02]\), Visual field of the word and Block \([F(1,21) = 7.14, p = .01]\), and the three-way interaction between Sex, Condition, and Presentation \([F(1,21) = 8.38, p = .009]\).

The interaction between Presentation and Visual field of the word is presented in Figure 3.1. Post-hoc analyses indicated that RTs for bilateral presentations did not differ as a function of the VF of the word, while for unilateral presentations the RVF condition was significantly faster than the LVF condition.
Figure 3.1

Interaction between Presentation and Visual field of the word for a lateralized Stroop task
(numbers in the figure represent p-values for pairwise comparisons of means)

The interaction between Sex and Block is shown in the Figure 3.2. Post-hoc analyses revealed that female participants improved with practice while males did not.

The interaction between Presentation and Block is presented in the Figure 3.3. RTs for unilateral presentations significantly decreased with practice, while RTs for bilateral presentations did not improve.

The interaction between Visual field of the word and Block is presented in Figure 3.4. Post-hoc analyses indicates that RTs for LVF-word, but not RVF-word, presentations improved with practice.
Figure 3.2

Interaction between Block and Sex for a lateralized Stroop task (numbers in the figure represent p-values for pairwise comparisons of means)

![Graph showing interaction between Block and Sex for a lateralized Stroop task.](image)

Figure 3.3

Interaction between Block and Presentation for a lateralized Stroop task (numbers in the figure represent p-values for pairwise comparisons of means)

![Graph showing interaction between Block and Presentation for a lateralized Stroop task.](image)
The 3-way interaction between Sex, Condition, and Presentation can be better understood from Figure 3.5 in which Incongruent - Congruent difference scores (i.e., the Stroop effect) were used as the dependent measure to simplify the interaction. As can be seen from Figure 3.5, males and females showed equivalent SE for unilateral trials whereas the SE was significantly greater for females than males for bilateral trials.

Figure 3.4

Interaction between Block and Visual field of the word for a lateralized Stroop task (numbers in the figure represent p-values for pairwise comparisons of means)

Additional ANOVAs (4-way) were performed separately for unilateral and bilateral trials to further tease apart Visual field effects. For unilateral trials, the levels of the Visual field factor are LVF and RVF, while for bilateral trials the levels are LVF-word/RVF-color and RVF-word/LVF-color. Since several of the significant effects
parallel that of the all trials analysis, only novel findings involving the Visual field factor will be presented.

Figure 3.5

Interaction between Condition, Presentation and Sex for a lateralized Stroop task, using Incongruent - Congruent difference scores as a dependent measure (numbers in the figure represent p-values for pairwise comparisons of means)

For unilateral trials, there was a significant main effect for Visual field [$F(1,21) = 12.73, p = .002$] with faster RTs for RVF ($M = 648.87$ msec) than for LVF ($M = 666.54$ msec). There were no significant interactions that included the Visual field factor.

For bilateral trials, the interaction between Visual field of the word and Block was significant [$F(1,21) = 5.73, p = .03$]. As can be seen in Figure 3.6, RTs during the second block were faster for LVF-word/RVF-color bilateral trials than for RVF-word/LVF-color,
while these conditions did not differ for the first block. However, for a given Visual field condition, there were no significant practice effects.

In summary, the results for the lateralized Stroop task indicated an overall interference effect which differed for the sexes: for unilateral presentations there was no difference between males and females, whereas for bilateral presentations males showed significantly smaller interference than females (see Figure 3.5). Overall, unilateral presentations were faster than bilateral presentations. Several effects of practice were found, whereby RTs improved over time for: females, but not males; for unilateral, but not bilateral trials; and for LVF-word, but not RVF-word trials. Finally, RTs were faster for unilateral RVF than for LVF presentations.

Figure 3.6

Interaction between Visual field of the word and Block for bilateral trials in the lateralized Stroop task (numbers in the figure represent the p-values for pairwise comparisons of means)
ERP Data

Typical ERPs waveforms for the lateralized Stroop task are presented in Figure 3.7. Several components were identified for Experiment 1: anterior N1/P1 complex, posterior P1/N1 complex, N2, and P3 component. As can be seen in Figure 3.7, there was no clear N2 component over the temporal and occipital sites for this task, therefore, the analyses for N2 will be carried out only for the frontal, central, and parietal sites.

For each complex and component, two principal analyses were performed, one for vertex sites and one for lateral sites. For vertex sites, mean amplitudes were entered into a 2x2x2x2x4 mixed factorial ANOVA with Sex (males, females) as a between subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (LVF, RVF), and Vertex site (Fz, Cz, Pz, and Oz) as within subject factors. For lateral sites, mean amplitudes were entered into a 2x2x2x2x5x2 mixed factorial ANOVA with Sex (males, females) as a between subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (LVF, RVF), Lateral site [frontal (F3/F4), central (C3/C4), temporal (T5/T6), parietal (P3/P4), and occipital (O1/O2)], and hemisphere (left sites, right sites) as within subject factors.
Figure 3.7

ERP waveforms for congruent and incongruent presentations in a lateralized Stroop Task.
**Anterior N1/P1 Complex - Mean Amplitude Between 100 and 220 msec**

**Vertex sites.** For vertex sites (i.e., Fz and Cz) an ANOVA only revealed a statistically significant 3-way interaction between Sex, Condition, and Presentation \( F(1,21) = 21.79, p = .0001 \). As shown in Figure 3.8, and supported by post-hoc analyses, males and females significantly differed in unilateral as well as in bilateral trials: for unilateral trials males showed significantly more negative mean amplitudes than females for congruent trials, while for bilateral presentations males showed more negative mean amplitudes than females for incongruent trials.

**Figure 3.8**

*Interaction between Sex, Condition, and Presentation for mean amplitudes of the anterior N1/P1 complex at vertex sites for a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)*
Additional analyses for just unilateral trials revealed a significant interaction between Sex and Condition \[ F(1,21) = 10.78, p = .004 \], which was present in the all trials analysis (see Figure 3.8). For just bilateral presentations there was a significant interaction between Sex, Condition, and Visual field of the word \[ F(1,21) = 15.15, p = .0008 \] as seen in Figure 3.9. Post-hoc analyses indicated that males and females significantly differed for RVF-word/LVF-color trials such that for males, amplitudes were significantly more negative for incongruent than for congruent trials, whereas the opposite pattern was present for females.

Figure 3.9

Interaction between Sex, Condition, and Visual field of the word for mean amplitudes of the anterior N1/P1 complex at vertex sites for bilateral trials in the lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)
Lateral sites. For lateral sites (i.e., F3, F4, C3, and C4) an ANOVA revealed a significant main effect for Lateral site \([F(1,21) = 8.57, p = .008]\) with the frontal sites having more positive amplitudes (.93 uV) than the central sites (.32 uV). There was also a statistically significant interaction between Sex, Condition, and Presentation \([F(1,21) = 17.41, p = .0004]\). This interaction is similar to the interaction found at the vertex sites (see Figure 3.8) and will not be further analyzed.

An ANOVA for just unilateral presentations revealed a significant interaction between Sex and Condition \([F(1,21) = 10.18, p = .004]\) and an interaction between Visual field and Hemisphere \([F(1,21) = 10.60, p = .004]\). The interaction between Sex and Condition was similar to the interaction found at the vertex sites (see Figure 3.8) and will not be further analyzed. The interaction between Visual field and Hemisphere is presented in Figure 3.10. Post-hoc analyses showed that the RVF trials evoked significantly more negative amplitudes over the LH (i.e., direct condition) than over the RH (i.e., indirect condition).

An ANOVA for bilateral presentations revealed a significant main effect for Lateral sites \([F(1,21) = 9.31, p = .006]\) and significant interaction between Sex, Condition, and Visual field of the word \([F(1,21) = 14.06, p = .001]\). These findings parallel previous ones and will not be further analyzed.
Figure 3.10

Interaction between Visual field and Hemisphere for mean amplitudes of the anterior N1/P1 complex at lateral sites for unilateral trials in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)

![Graph showing interaction between visual field and hemisphere for mean amplitudes.]

Posterior P1/N1 Complex - Mean Amplitude Between 90 and 220 msec

**Vertex sites.** For the vertex sites (i.e., Pz and Oz) an ANOVA revealed a significant main effect for Vertex site \( F(1,21) = 12.41, p = .002 \) with more negative amplitudes for Oz (-1.14 uV) than for Pz (-1.0 uV). There was also a statistically significant interaction between Sex, Condition, and Presentation \( F(1,21) = 14.39, p = .001 \), as seen in Figure 3.11. Post-hoc analyses indicated sex differences. For unilateral presentations there was a non-significant trend \( p = .06 \) whereby males showed less negative amplitudes than females for incongruent trials, while for bilateral presentations males showed less
negative amplitudes than females for congruent trials. However, there were no ERP Stroop effects.

Figure 3.11

Interaction between Sex, Condition, and Presentation for mean amplitudes of the posterior P1/N1 complex at vertex sites for a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)

The ANOVA for unilateral presentations showed a significant main effect for Vertex site \([F(1,21) = 14.68, p = .001]\), consistent with the all trials analysis. For bilateral presentations, the ANOVA revealed a significant main effect for Vertex site \([F(1,21) = 10.06, p = .004]\), consistent with the all trials analysis, and a significant main effect for Visual field of the word \([F(1,21) = 17.67, p = .0003]\), in which amplitudes were more negative for the LVF-color/RVF-word trials (-1.26 \(\mu\)V) than for then for LVF-word/RVF-color trials (-.58 \(\mu\)V).
Lateral sites. For the lateral sites (i.e., T5, T6, P3, P4, O1, and O2) an ANOVA revealed a significant main effect for Lateral site \( [F(2,42) = 6.43, p = .004] \). Post-hoc analyses showed that occipital (-1.33 uV) and temporal (-1.22 uV) sites were significantly more negative than the parietal sites (-.56 uV). There was also a statistically significant 2-way interaction between Visual field of the word and Hemisphere \([E(1,21) = 15.78, p = .0007]\), a 3-way interaction between Sex, Condition, and Presentation \([E(1,21) = 12.25, p = .002]\), and a 3-way interaction between Presentation, Visual field of the word, and Hemisphere \([E(1,21) = 10.78, p = .004]\). The 3-way interaction between Sex, Condition, and Presentation was equivalent to the one found in the previous analysis of vertex sites and will not be further elaborated.

The interaction between Presentation, Visual field of the word, and Hemisphere is presented in figure 3.12. Post-hoc analyses showed that significant differences occurred in unilateral presentations for the RH: the LVF presentations (i.e., direct access) generated more negative mean amplitudes than the RVF presentations (also seen in Figure 3.10 for the anterior N1/P1 complex).

An ANOVA for posterior P1/N1 mean amplitudes for unilateral trials revealed a significant main effect for Lateral site \([F(2,42) = 7.07, p = .002]\), a significant interaction between Sex and Condition \([F(1,21) = 13.92, p = .001]\) which can be seen in Figure 3.11, and a significant interaction between Visual field and Hemisphere \([F(1,21) = 13.92, p = .001]\) which can be seen in Figure 3.12.

For bilateral presentations, the ANOVA showed a statistically significant main effect of Visual field of the word \([F(1,21) = 24.63, p < .0001]\) and a 3-way interaction
between Visual field of the word, Lateral site, and Hemisphere \( F(2,42) = 8.14, p = .001 \).

Results showed that the LVF-word/RVF-color trials evoked less negative amplitudes (-88 uV) than the RVF-word/LVF-color trials (-1.57 uV).

**Figure 3.12**

*Interaction between Presentation, Visual field of the word, and Hemisphere for mean amplitude of the posterior P1/N1 complex at lateral site in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)*

The interaction between Visual field of the word, Lateral site, and Hemisphere is shown in Figure 3.13. Post-hoc analyses indicated that over the temporal sites the posterior P1/N1 complex was significantly more negative over the LH than the RH, and this occurred irrespective of the VF in which the word was presented. The same pattern was observed at the occipital sites but only for the LVF-word/RVF-color trials.
For the posterior P1/N1 complex two additional analyses, with the same mixed factorial design, were performed for lateral sites using peak amplitudes rather than mean amplitudes as a dependent measure: separate analyses were done for positive peak amplitudes and for negative peak amplitudes.

Figure 3.13

Interaction between Visual field of the word, Lateral site, and Hemisphere for mean amplitudes of the posterior P1/N1 complex at lateral sites for bilateral presentations in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)

Posterior P1/N1 Complex - Positive Peak Amplitudes

An ANOVA for positive peak amplitudes revealed a significant 2-way interaction between Presentation and Site \[F(2,42) = 8.92, p = .001\] and 3-way interaction between
Sex, Condition, and Presentation \( F(1,21) = 12.30, p = .002 \). The three way interaction between Sex, Condition, and Presentation parallels the interaction already reported for mean amplitudes. The interaction between Presentation and Site is shown in Figure 3.14. Post-hoc analyses indicated that amplitudes were greater for unilateral than for bilateral presentations at the temporal and parietal sites only.

ANOVAs for posterior positive peak amplitudes for separate analyses of unilateral presentations and bilateral presentations did not show any significant effects.

Figure 3.14

Interaction between Presentation and Lateral site for positive peak amplitudes of the posterior P1/N1 complex in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)
Posterior P1/N1 Complex - Negative Peak Amplitudes

An ANOVA for negative peak amplitudes revealed a significant main effect of Lateral site \( [F(2,42) = 8.92, p = .001] \). Post-hoc analyses showed that temporal (-6.04 \( \mu \)V) and occipital sites (-5.78 \( \mu \)V) significantly differed from the parietal sites (-4.93 \( \mu \)V). There were also a statistically significant 2-way interaction between Visual field of the word and Hemisphere \( [F(1.21) = 9.28, p = .006] \), a 3-way interaction between Sex, Condition, and Presentation \( [F(1.21) = 8.02, p = .01] \), and a two 4-way interactions: Sex, Condition, Presentation, and Hemisphere \( [F(2,42) = 12.98, p = .002] \), and Sex, Presentation, Lateral site, and Hemisphere \( [F(2,42) = 6.45, p = .007] \).

The interactions between Visual field of the word and Hemisphere and between Sex, Condition, and Presentation parallel those from the analysis with mean amplitudes and will not be further elaborated. Due to the complexity of the 4-way interactions and the relatively small sample size for each sex, these results were not further analyzed.

Additional analyses for unilateral presentation revealed a statistically significant main effect for Lateral site \( [F(2,42) = 5.31, p = .01] \), a significant 2-way interaction between Sex and Condition \( [F(1,21) = 7.96, p = .01] \), a significant 2-way interaction between Visual field and Hemisphere \( [F(1,21) = 9.10, p = .007] \), and a 3-way interaction between Sex, Condition and Hemisphere \( [F(1,21) = 10.22, p = .004] \). The main effect of Lateral site and interaction between Visual field and Hemisphere have been already addressed in all trial analyses. Again, interactions involving sex were not further analyzed for reasons outlined above.
An ANOVA for bilateral presentations showed a statistically significant main effect for Lateral site \([F(2,42) = 5.86, p = .01]\), as was present in the analysis of all trials. There was also a significant main effect for Visual field of the word \([F(1,21) = 26.44, p = <.0001]\), with LVF-color/RVF-word trials exhibiting more negative amplitudes (-6.02 uV) than LVF-word/RVF-color trials (-5.22 uV). There was also a statistically significant interaction between Visual field of the word, Lateral site and Hemisphere \([F(2,42) = 9.08, p = .0005]\), as shown in Figure 3.15. Post-hoc analyses showed that LVF-color/RVF-word trials generated more negative amplitudes at all sites over both hemispheres, with the exception of the temporal site over the RH.

Figure 3.15

Interaction between Visual field, Lateral site, and Hemisphere for negative amplitudes of the posterior P1/N1 complex for bilateral trials at lateral sites in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)
**Posterior P1/N1 Complex - Peak Latencies**

Peak latency measurements of the P1 and N1 components at the temporal, parietal and occipital sites over both hemispheres for LVF and RVF unilateral presentations as well as difference between ipsilateral and contralateral peak latencies, also referred as Interhemispheric Transfer Time (IHTT), are presented in Tables 3.1 and 3.2. Latencies shifts for earlier P1 are between 35 and 48 msec, while the latency shifts for N1 components are between 15 and 28 msec. Contralateral projections to the temporal sites over both hemispheres generated earlier peak amplitudes for P1 and N1 components than ipsilateral projections, as shown in Figure 3.16. Latency shifts of the P1 and N1 components are.

Table 3.1

Peak latencies (msec) of the posterior P1 component for temporal, parietal and occipital sites over both hemispheres for ipsilateral VF and contralateral VF presentations in a lateralized Stroop task (IHTT signifies Inter-Hemispheric Transfer Time).

<table>
<thead>
<tr>
<th>Site</th>
<th>LH</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ipsilateral</td>
<td>Contralateral</td>
</tr>
<tr>
<td>Temporal</td>
<td>135</td>
<td>96</td>
</tr>
<tr>
<td>Parietal</td>
<td>129</td>
<td>93</td>
</tr>
<tr>
<td>Occipital</td>
<td>132</td>
<td>90</td>
</tr>
</tbody>
</table>
components due to direct or indirect projection of the Stroop stimuli indicated that the IHTTs were shorter for the N1 component (M = 23 msec) than for P1 component (M = 40 msec).

Table 3.2

Peak latencies (msec) of the posterior N1 component for temporal, parietal and occipital sites over both hemispheres in a lateralized Stroop task (IHTT signifies Inter-Hemispheric Transfer Time)

<table>
<thead>
<tr>
<th>Site</th>
<th>LH Ipsilateral</th>
<th>LH Contralateral</th>
<th>LH IHTT</th>
<th>RH Ipsilateral</th>
<th>RH Contralateral</th>
<th>RH IHTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal</td>
<td>195</td>
<td>171</td>
<td>24</td>
<td>195</td>
<td>167</td>
<td>28</td>
</tr>
<tr>
<td>Parietal</td>
<td>183</td>
<td>165</td>
<td>18</td>
<td>174</td>
<td>159</td>
<td>15</td>
</tr>
<tr>
<td>Occipital</td>
<td>195</td>
<td>171</td>
<td>24</td>
<td>195</td>
<td>168</td>
<td>27</td>
</tr>
</tbody>
</table>

N2 Component - Mean Amplitude Between 220 and 300 msec

Vertex sites. An ANOVA for vertex sites showed only a statistically significant main effect for Vertex site \[F(2,42) = 5.63, p = .01\], with more negative amplitudes over the frontal site (.33 uV), followed by the central site (.90 uV), and least negative mean amplitude over the parietal site (1.96 uV). Post-hoc analyses indicated that the three sites significantly differed from each other. The same finding was obtained for bilateral trials \[F(2,42) = 6.11, p = .01\], but not for unilateral trials.
Figure 3.16

ERP waveforms for left (T5) and right (T6) temporal sites during unilateral LVF and RVF presentations of Stroop stimuli in a lateralized Stroop task. Note the latency and amplitude differences between contralateral and ipsilateral VF-hemisphere conditions.

Lateral sites. An ANOVA showed only a statistically significant 4-way interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere \[F(2,42) = 6.95, \ p = .007\], which is presented in Figure 3.17. For unilateral trials post-hoc analyses indicated more negative amplitudes for RVF presentations than for LVF presentations over the LH at the frontal and central sites. For bilateral presentations, however, there were more negative amplitudes generated by LVF-color/RVF-word presentations than for
LVF-word/RVF-color presentations for the central and parietal sites over both hemispheres.

An additional ANOVA for unilateral trials revealed a significant 2-way interaction between Visual field and Hemisphere \( F(1,21) = 10.82, p = .003 \) and 3-way interaction between Visual field, Lateral site, and Hemisphere \( F(2,42) = 5.39, p = .01 \) which were presented in Figure 3.17.

An ANOVA for bilateral trials revealed a significant main effects for Visual field of the word \( F(1,21) = 8.86, p = .007 \]. LVF-color/RVF-word trials evoked more negative amplitudes (.78 uV) than LVF-word/RVF-color trials (1.37 uV).

**P3 Component - Mean Amplitude Between 300 and 500 msec**

**Vertex sites.** An ANOVA for vertex sites showed a statistically significant main effect for Condition \( F(1,21) = 10.45, p = .004 \], with greater amplitudes for congruent trails (8.51 uV) than for incongruent trails (7.85 uV). There was also a significant main effect of Vertex site \( F(3,63) = 27.11, p < .0001 \]. Post-hoc analyses indicated that the parietal site (11.33 uV) generated significantly more positive mean amplitudes than the frontal (5.29 uV), central (8.61 uV), and occipital (7.48 uV) sites. Furthermore, central and occipital sites did not significantly differ but their respective mean amplitudes were significantly greater than the mean amplitude at the frontal site.

Additional analyses for unilateral trials showed a significant main effect for Condition \( F(1,21) = 26.94, p < .0001 \]. For bilateral trials there was also a significant main effect for Condition \( F(1,21) = 7.99, p = .01 \] in addition to a significant main effect...
Figure 3.17

Interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere for mean amplitudes of the N2 component at lateral sites in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)

A) Unilateral presentations

B) Bilateral presentations
for Vertex site \([F(3,63) = 26.20, p < .0001]\). These effects parallel the effects for the all trails analysis and will not be further analyzed.

**Lateral sites.** For lateral sites the ANOVA showed a statistically significant main effect of Condition \([F(1,21) = 8.61, p = .008]\) and a significant main effect of Lateral site \([F(4,84) = 12.60, p < .0001]\). These two effects are equivalent to those found at the vertex sites. There were several statistically significant interactions: Visual field of the word and Hemisphere \([F(1,21) = 14.39, p = .001]\), Presentation, Visual field of the word, and Hemisphere \([F(1,21) = 11.75, p = .003]\), Visual field of the word, Lateral sites, and Hemisphere \([F(4,84) = 10.21, p < .0001]\), Condition, Presentation, Visual field of the word, and Lateral sites \([F(4,84) = 7.55, p = .002]\), and Presentation, Visual field of the word, Lateral sites, and Hemisphere \([F(4,84) = 8.68, p < .0001]\). Only the two four-way interactions will be discussed since the lower order interactions can be explained by the effects in the higher order interactions.

The interaction between Condition, Presentation, Visual field of the word, and Lateral site is presented in Figure 3.18. For unilateral trials, post-hoc analyses indicated that the congruent condition for RVF, but not for LVF, presentations generated greater amplitudes than incongruent condition at posterior, but not anterior, sites. In other words, at posterior sites there was a P3 SE for RVF but not for LVF presentations. For the bilateral presentations, the congruent trials also generated greater amplitudes than incongruent trials under certain conditions. In general, when the word was presented in the LVF (color in the RVF) there was a P3 SE over central, parietal and occipital sites. When the word was presented in the RVF (color in the LVF) there was a P3 SE over the
Figure 3.18

Interaction between Condition, Presentation, Visual field of the word, and Lateral site for P3 mean amplitudes at lateral sites in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means)

A) Unilateral presentations

B) Bilateral presentations
Simple interaction between Condition, Visual field, and Hemisphere for P3 mean amplitudes for unilateral trials at left (P3) and right (P4) parietal sites in a lateralized Stroop task.

Given that the P3 was largest over the parietal site, further analysis of the apparent lateralized P3 SE was performed for just this region. A simple interaction effect between VF and parietal site (P3-LH and P4-RH) was found for the incongruent condition \[ F(1,21) = 5.65, p = .03 \], but not for the congruent condition \( p = .68 \). As seen in Figure 3.19, at the LH, but not RH, parietal site direct projection (i.e., from the RVF) of
incongruent stimuli generated smaller P3 amplitudes than indirect projections of incongruent trials (i.e., from the LVF).

The second significant 4-way interaction (between Presentation, Visual field of the word, Lateral sites, and Hemisphere) is presented in Figure 3.20. For unilateral trials, post-hoc analyses indicated, surprisingly, that over the LH, amplitudes were larger for ipsilateral (LVF) than for contralateral (RVF) presentations for all three posterior sites. A similar pattern was found over the RH, but only for temporal and occipital sites. Larger P3 amplitudes for ipsilateral than for contralateral VF-Hemisphere combination can be seen for temporal sites in Figure 3.16. For bilateral presentations, post-hoc analyses showed that the presentations with the word in the LVF (color in the RVF) evoked greater amplitudes over both hemispheres than the presentations with the word in the RVF (color in the LVF). These findings were corroborated by a statistically significant 3-way interaction between Visual field, Lateral site, and Hemisphere for unilateral presentations \([F(4,84) = 13.32, p < .0001]\) but not for bilateral presentations.

The ANOVA for unilateral presentations revealed a significant main effect for Lateral site \([F(4,84) = 12.54, p < .0001]\), a significant interaction between Visual field and Hemisphere \([F(1,21) = 21.28, p = < .0002]\), 3-way interactions between Condition, Visual field, and Lateral site \([F(4,84) = 4.28, p = .01]\) and between Visual field, Lateral site, and Hemisphere \([F(4,84) = 113.32, p < .0001]\). For bilateral presentations there was only a statistically significant main effect for Lateral site \([F(4,84) = 12.17, p < .0001]\). All these effects have been addressed in the analysis for all trials (see Figure 3.18 and Figure 3.19).
Interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere for P3 mean amplitudes at lateral sites in a lateralized Stroop task (numbers in figure represent p-values for pairwise comparisons of means).

A) unilateral presentations

B) bilateral presentations
P3 Component - Peak Amplitudes and Latencies

Additional ANOVAs were performed for the P3 component, using peak amplitudes and peak latencies as dependent measures. In general, peak amplitudes yielded the same findings as the analyses with mean amplitudes. The ANOVAs from peak latencies as a dependent measure indicated only a significant main effect of Lateral site for bilateral presentations \( [F(4,84) = 4.82, p = .01] \). Post-hoc analyses indicated that latencies at the frontal sites (383 msec) were significantly shorter than latencies at the temporal (402 msec) and occipital sites (401 msec), while central (391 msec) and parietal (394 msec) sites had intermediate latencies that did not significantly differ from those of other sites. Importantly, P3 latencies were unaffected by task condition.

Summary

For the exogenous anterior N1/P1 complex and the posterior P1/N1 complex, several multiway interaction were found involving sex and other experimental factors, particularly Stroop conditions. Given that these are presumably exogenous components that are known to be driven by perceptual rather than cognitive factors, these effects were surprising and will not be further summarized. The additional experiments in this dissertation should help clarify whether these effects are spurious or real.

N1/P1 anterior complex. Results for the exogenous anterior N1/P1 complex showed that there was greater amplitude over the frontal than the central lateral sites. There was also tendency for more negative amplitudes for direct VF-Hemisphere conditions than for indirect conditions, although this was only significant for the RVF presentations (see Figure 3.10).
**P1/N1 posterior complex.** Posterior P1/N1 complex mean amplitudes were more positive over the occipital and temporal sites, than for the parietal sites. At the posterior sites unilateral presentations showed marked latency shifts between ipsilateral and contralateral projections, resulting in an average IHTT of approximately 31 msec for P1 and N1 peaks, respectively (see Figure 3.16). There was also a tendency for more negative amplitudes for direct VF-Hemisphere conditions than for indirect conditions for both unilateral VFs. On the other hand, bilateral presentations generated more negative amplitudes over the LH than over the RH at the temporal sites irrespective of which VF a word was presented (see Figure 3.13). Greater mean negativity over the LH than over the RH was also observed at occipital sites but only for the LVF-word/RVF-color trials. Separate analyses for positive peak amplitudes indicated greater positivity for unilateral than for bilateral presentations over the temporal and parietal sites. Analyses for negative peak amplitudes showed that LVF-color/RVF-word trials generated more negative amplitudes than LVF-word/RVF-color trials at all sites over both hemispheres, with exception of the temporal site over the RH (see Figure 3.15).

**N2 component.** For vertex sites but not for lateral sites, N2 mean amplitudes were most negative over the frontal sites and least negative over the parietal sites. For unilateral presentations the mean amplitudes were more negative over the LH for RVF trials (i.e., direct projections) than for LVF trials (see Figure 3.16 A). However, for bilateral presentations, the LVF-color/RVF-word trials generated more negativity than the LVF-word/RVF-color trials over the central and parietal sites over both hemispheres (see Figure 3.17 B).
**P3 component.** A main effect of Condition (congruent vs incongruent) was first observed for the P3 component with greater amplitudes for congruent than for incongruent presentations. The greatest amplitudes were observed over the parietal sites. P3 peak latency, in contrast, was earliest over the frontal sites. For unilateral LVF presentations, P3 amplitudes did not differ for congruent and incongruent conditions. However, for unilateral RVF presentations P3 amplitudes were larger for congruent than for incongruent conditions at posterior sites (see Figure 3.18 A). Separate analyses for incongruent unilateral trials revealed that the parietal site over the LH, but not over the RH, showed smaller amplitudes for direct VF than for indirect VF presentations (see Figure 3.19). For bilateral presentations, LVF-word/RVF-color and LVF-color/RVF-word congruent trials generated greater amplitudes than incongruent trials over the central and the parietal sites, and only LVF-word/RVF-color trials generated greater amplitudes over the occipital site. In addition, localized SEs were observed, depending on the VF of the word: for word in the LVF presentations the congruent trials generated greater amplitudes than the incongruent trials over parietal sites, while for the word in the RVF presentations, there were greater amplitudes for the congruent than incongruent trials over the frontal sites (see Figure 3.18 B). With respect to hemispheric asymmetries, bilateral presentations showed larger amplitudes over all sites and over both hemispheres for the LVF-word/RVF-color compared to the LVF-color/RVF-word condition (see Figure 3.20 B). For unilateral presentations, over both hemispheres, the temporal and the occipital sites exhibited larger amplitudes for ipsilateral VF presentations (see Figure 3.20 A). This was also the case for left parietal (P3), but not right parietal (P4), recordings.
Discussion

Behavioral Data

Lateralized presentations of Stroop stimuli were utilized to investigate hemispheric asymmetries of the Stroop interference effect. It was assumed that there would be a greater SE when the word was presented to the RVF irregardless of the VF of the color patch. Experiment 1 showed an overall SE of 36 msec, however, there was no evidence for VF differences in the SE. The only SE related to hemispheric asymmetries was that for bilateral presentations where females showed a greater SE than males. This finding is in accordance with sex differences in callosal connectivity (Witelson, 1990), whereby greater callosal connectivity in females than in males may account for the greater interhemispheric SE in females. Lateralized presentation of the Stroop task did not change the SE across blocks. However, there was an overall practice effect for females, but not for males. Sex differences in practice may reflect differences in motivation or in performance strategies. In addition, the performance of the unilateral, but not bilateral, trials improved with practice, suggesting that unilateral trials were easier to learn. The remaining experiments in this dissertation will help to assess the reliability of these practice effects.

ERP Data

Laterality effects - direct versus indirect anatomical pathways. Early laterality effects due to the VF-hemisphere combinations for unilateral presentations were found across the anterior N1/P1 and posterior P1/N1 complexes. It was predicted that for unilateral presentations these early components should have larger amplitudes and earlier peak
latencies for direct than for indirect VF-hemisphere combinations due to the shorter anatomical pathways for the direct than for the indirect condition. This general pattern was found for the anterior N1/P1 complex (see Figure 3.10) and for the posterior N1 component (see Figure 3.16). However, such early laterality effects were more reliable over the RH than over the LH. In addition, ERP measurements of IHTT at posterior sites were greater for the earlier P1 component (i.e., 36 - 48 msec) than for the subsequent N1 component (i.e., 15 - 28 msec). The difference in IHTTs between the P1 and N1 components may reflect involvement of different callosal channels with different conduction velocities. Unexpectedly, paradoxical laterality effects were observed as late as the P3 component at temporal sites (see Figure 3.20). For unilateral presentations, there were greater P3 amplitudes for ipsilateral than for contralateral presentations over both hemispheres. One possible explanation for this finding could be that the P3 amplitudes were affected by a carry-over effect from the preceding N1 component (see Figure 3.16). In this view, larger N1 amplitudes result in the smaller P3 amplitudes.

**Laterality effects - hemispheric specialization.** The first evidence for hemispheric specialization occurred, surprisingly, very early at the posterior P1/N1 complex. The posterior N1 component at temporal sites for bilateral presentations may be revealing a very early hemispheric differences in language organization, because LVF-color/RVF-word presentations generated more negative amplitudes than LVF-word/RVF-color presentations over the language specialized LH but not over the RH (see Figure 3.15). Hemispheric specialization effects continued for the N2 component which was most pronounced at anterior sites. Over the language specialized LH, the anterior N2
component tended to be larger when the word and color were presented directly to the LH rather than to the RH initially (see figure 3.17 A). In contrast, over the RH there was no difference between LVF and RVF unilateral presentations. These findings indicate that the N2 may reflect hemispheric specialization for language processing. However, for bilateral trials, there were greater amplitudes over both hemispheres when the word was projected to the LH and the color to the RH. This finding indicates that brain functioning reflects the precedence of the LH (RVF) word presentation during bilateral stimulation. Therefore, for the N2 component it is possible to distinguish between intrahemispheric from interhemispheric interactions by contrasting the findings from unilateral and bilateral presentations as related to the VF-hemisphere combinations.

SE. Unexpectedly, effects of the lateralized Stroop paradigm were first observed for the exogenous anterior N1/P1 and posterior P1/N1 components, albeit in the form of relatively complex interactions that usually included sex. These findings indicate that there may be a very early SE that differs for males and females. However, an early SE may represent spurious results due to the relatively small sample size for males and females. Interpretation of these effects will be aided by the subsequent experiments. The next occurrence of the SE was for the endogenous P3 component. Surprisingly, the congruent condition generated greater amplitudes than the incongruent condition. If the P3 can be considered a measure of stimulus evaluation, then greater amplitudes for congruent than for incongruent trials may reflect the ease of processing or reduced processing load. In this view, the easier congruent trials generate greater amplitudes than the more difficult incongruent trials. The incongruent trials must be more difficult for the
simple reason that they involve obligatory inhibition of the incongruent word information. By the same token, incongruent trials represent greater processing load than congruent trials due to obligatory inhibition of the word, and therefore, incongruent trials generated smaller P3 amplitudes. For unilateral presentations, however, this P3 SE only occurred for RVF presentations, and only over temporal, parietal and occipital sites (see Figure 3.18 A). This electrophysiological finding of the SE is in the hypothesized direction, whereby RVF presentations to the language specialized LH show a greater SE than LVF presentations. In addition, there was a difference between the two hemispheres at the parietal sites for the incongruent unilateral trials: the LH, but not the RH, showed smaller P3 amplitudes for contralateral than for ipsilateral presentations (see Figure 3.19). If smaller P3 amplitudes reflect greater interference, then the previous finding may be considered additional electrophysiological evidence for a greater SE over the LH when incongruent stimuli are presented directly to the LH. Recall, that the behavioral data did not show any evidence for VF differences in the SE, thus ERPs measures may be more sensitive for revealing hemispheric differences for the SE. However, at the parietal sites where P3 amplitudes were the largest, bilateral presentations generated greater amplitudes for congruent than for incongruent presentations irrespective of which hemisphere received the word or color. For bilateral presentations, interhemispheric transfer of information is presumably automatic, which, in turn, generates interhemispheric interactions that apparently do not depend on the specific VF of the word or color presentation. Results from the lateralized Stroop task also support Duncan-Johnson and Kopell’s (1981) finding of a lack of P3 peak latencies differences between congruent and
incongruent presentations despite RT differences between these conditions. Whereas RTs were 36 msec longer for incongruent than for congruent trials, no such latency differences were apparent for P3 peak latencies. However, the findings from this experiment do not support Duncan-Johnson and Kopell’s conclusion that the SE occurs after P3 peak amplitude because SEs were found for P3 amplitude even if they weren’t found for P3 latencies. Thus, P3 amplitudes may be associated with a component of the SE that is earlier than, and independent of, the effects on RTs.

The main purposes for the Experiment 2 were to determine whether an N4 component is also produced by a Stroop paradigm, and if the SE is present for a delayed motor response. Following Kutas’s argument that the P3 component may overlap and mask an N4 component, a lateralized Stroop task with a delayed matching response was designed. Delaying a motor response has been shown to greatly reduce P3 amplitudes, which way uncover an inherent N4 component. To my knowledge, no study has been conducted with a delayed matching response for the Stroop paradigm. However, the prediction of the relative speed of processing model would be that with a delayed matching response there would be no SE, because the SE is based on the response competition for the two components. In the lateralized Stroop task with delayed matching response, the participants will have to categorize the color of a probe subsequent target as the ‘same’ or ‘different’ from the color patch of the preceding Stroop stimuli. Ergo, according to the relative speed of processing model, there should be no response competition and consequently no SE.
EXPERIMENT 2: LATERALIZED STROOP TASK WITH DELAYED MATCHING RESPONSE

In Experiment 2, participants were presented with the same set of lateralized Stroop stimuli in a similar fashion as in Experiment 1. Unlike Experiment 1, however, participants were to respond following a 700 msec delay, after which a target (i.e., a colored patch) appeared in the center of the monitor. After the target presentation, participants were asked to identify the target as the ‘same’ or ‘different’ as compared to the color patch of the Stroop stimulus.

Behavioral Data

Reaction times were entered into a 2x2x2x2x2x2 factorial ANOVA, with Sex (male, female) as a between-subjects factor and Match ('same', 'different'), Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (left visual field - LVF, right visual field - RVF), and Block (block 1, block 2) as within subjects factors. All post-hoc analyses were carried out using the Tukey honestly significant difference (HSD) test.

The analysis of RTs revealed a significant main effect of Match [$F(1,19) = 4.99, p = .04$] with faster RTs for 'same' trials (i.e., the probe and the target were the same) ($M = 587$ msec) than for 'different' trials ($M = 603$ msec). There was also a statistically significant main effect of Condition [$F(1,19) = 34.27, p < .00005$] with faster RTs for congruent trials ($M = 588$ msec) than for incongruent trials ($M = 602$ msec).

The ANOVA also revealed a statistically significant 2-way interaction between Sex and Presentation [$F(1,19) = 5.97, p = .02$], a 3-way interactions between Sex, Match
and Condition \([F(1,19) = 5.51, \ p = .03]\), and a 3-way interaction between Match, Visual field of the word, and Block \([F(1,19) = 4.52, \ p < .05]\).

The interaction between Sex and Presentation is presented in Figure 3.21. Post-hoc analyses showed that males were faster for the unilateral than for the bilateral presentations, while RTs for females were equivalent for the two presentation modes.

**Figure 3.21**

*Interaction between Sex and Presentation for a lateralized Strop task with delayed matching response (numbers in the figure represent p-values for comparisons between pairwise means)*

The 3-way interaction between Sex, Match, and Condition is presented in Figure 3.22, albeit simplified by using Incongruent - Congruent difference scores (i.e., SE scores). Post-hoc analyses showed that males showed equivalent SE for 'same' and 'different' trials, while females showed a SE only for 'different' trials.
The 3-way interaction between Match, Visual field of the word, and Block is presented in Figure 3.23. Post-hoc analyses showed that practice only affected RTs for the word in the LVF trials such that only 'same' trials improved in the second block.

Figure 3.22
Interaction between Sex, Match, and Condition for a lateralized Stroop task with delayed matching response, using Incongruent - Congruent difference scores as a dependent measure (numbers in the figure represent p-values for comparisons between pairwise means)

Additional ANOVAs (4-way) were performed separately for unilateral and bilateral presentations to further tease apart Visual field effects. For unilateral trials, the levels of the Visual field factor are LVF and RVF, while for bilateral trials the levels are LVF-word/RVF-color and LVF-color/ RVF-word. Since several of the significant effects
parallel that of the 6-way analysis, only novel findings involving the Visual field factor will be presented.

Figure 3.23

Interaction between Sex, Match, and Condition for a lateralized Stroop task with delayed matching response, (numbers in the figure represent p-values for comparisons between pairwise means)

The ANOVA for unilateral trials did not reveal any additional findings with respect to the Visual field factor, while for bilateral trials there was a statistically significant 2-way interaction between Match and Visual field \( F(1,19) = 14.10, p = .001 \), as shown in Figure 3.24. Post-hoc analyses indicated that the LVF-word/RVF-color presentations were faster in 'same' condition than the 'different' condition. In addition, for the 'different' condition, the LVF-color/RVF-word trials were faster than LVF-word/RVF-color trials.
Overall, the finding of a significant SE (of about 14 msec) with a delayed matching response indicated that the SE persisted at least 700 msec after the stimulus onset when a delayed color matching, rather than immediate color identification, was required. Additional findings showed that the RTs for 'same' trials were faster than for 'different' trials. With respect to sex differences, the results indicated that males showed equal SE for 'same' and 'different' trials while females showed a SE only for 'different' trials, suggesting a strategy differences between the sexes. Furthermore, there was a large sex difference in RTs for the bilateral condition, suggesting a sex difference in interhemispheric interactions. Regarding hemispheric asymmetries, the results indicated that the overall processing for bilateral presentations with 'different' targets was faster for
the initial projection of the word to the language dominant hemisphere (i.e., LH) and the color to the RH than for initial projection of the word to the language non-dominant hemisphere (i.e., RH) and the color to the LH, as suggested by Figure 3.24.

**ERP Data**

In Experiment 2, participants matched a laterally presented color patch of the Stroop stimuli with the foveally presented target color which appeared 700 msec after the onset of the Stroop stimulus. The ERP analyses were based on an epoch that contained the presentation of the Stroop stimuli, as was the case in Experiment 1. Typical ERPs waveforms for this task are presented in Figure 3.25. The same components were identified for Experiment 2 as for Experiment 1: the anterior N1/P1 complex, posterior P1/N1 complex, N2, and P3 components.

For each complex and component, two principle analyses were performed, one for vertex sites and one for lateral sites. For vertex sites, mean amplitudes were entered into a 2x2x2x2x4 mixed factorial ANOVA with Sex (males, females) as a between subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (LVF, RVF), and Vertex site (Fz, Cz, Pz, and Oz) as within subject factors. Lateral sites had a similar design except that the Vertex site factor was replaced by two other factors: Lateral site [frontal (F3/F4), central (C3/C4), temporal (T5/T6), parietal (P3/P4), and occipital (O1/O2)], and Hemisphere (left sites, right sites).
Figure 3.25

ERP waveforms for congruent and incongruent presentations in a lateralized Stroop Task with delayed matching response
Anterior N1/P1 Complex- Mean Amplitude Between 100 and 220 msec

**Vertex sites.** For vertex sites (i.e., Fz and Cz) ANOVAs did not reveal any statistically significant effects for the all trial analyses or for separate unilateral and bilateral analyses.

**Lateral sites.** For lateral sites (i.e., F3, F4, C3, and C4) an ANOVA revealed a significant main effect for Sex \[F(1,19) = 10.32, p = .005\] with males showing more negative amplitudes (.98 uV) than females (2.14 uV). The same pattern was found for the unilateral trials \[F(1,19) = 9.72, p = .005\] and for the bilateral trials \[F(1,19) = 7.04, p = .01\].

Posterior P1/N1 Complex- Mean Amplitudes Between 90 and 220 msec

**Vertex sites.** For the vertex sites (i.e., Pz and Oz) ANOVAs did not reveal any statistically significant effects for the all trial analyses or for separate unilateral and bilateral analyses.

**Lateral sites.** For the lateral sites (i.e., T5, T6, P3, P4, O1, and O2) an ANOVA revealed a significant 2-way interaction between Visual field of the word and Hemisphere \[F(1,19) = 14.72, p = .001\] and a 3-way interaction between Presentation, Visual field of the word, and Hemisphere \[F(1,19) = 18.51, p = .0004\]. The interaction between Presentation, Visual field of the word, and Hemisphere, which also contains the 2-way interaction between Visual field of the word and Hemisphere, is presented in Figure 3.26. For unilateral, but not for bilateral, presentations direct VF conditions produced more negative amplitudes than indirect VF conditions over both hemispheres.
An ANOVA for posterior P1/N1 mean amplitudes for unilateral trials revealed a significant interaction between Visual field and Hemisphere \([F(1,19) = 20.76, \ p = .0002]\), a 3-way interaction between Sex, Lateral site, and Hemisphere \([F(1,19) = 5.38, \ p = .01]\), and a 4-way interaction between Sex, Condition, Visual field and Hemisphere \([F(1,21) = 10.00, \ p = .01]\). The interaction between Visual field and Hemisphere parallels that for the all trials analyses (see Figure 3.26). The 4-way interaction between Sex, Condition, Visual field and Hemisphere will not be further analyzed due to the small sample size of males and females.
Posterior P1/N1 Complex - Positive Peak Amplitudes

An ANOVA for positive peak amplitudes did not reveal any significant effects.

Posterior P1/N1 complex - negative peak amplitudes

An ANOVA for negative peak amplitudes showed a significant interaction between Presentation, Visual field of the word, and Hemisphere \[F(1,19) = 10.60, p = .004\], which parallel findings with mean amplitudes, as shown in Figure 3.26. There was also a significant 4-way interaction between Presentations, Visual field of the word, Lateral site, and Hemisphere \[F(2,38) = 7.85, p = .001\], as shown in Figure 3.27. Post-hoc analyses indicated a general pattern whereby the unilateral contralateral projections (i.e., direct projection) generated significantly more negative amplitudes than the ipsilateral projections (i.e., indirect projections) over the LH temporal site and over the RH temporal and parietal sites. For bilateral presentations, however, the LVF-color/RVF-word trials generated more negative amplitudes than LVF-word/RVF-color trials at the temporal site over the LH only.

Additional analyses for unilateral presentation revealed a statistically significant interaction between Visual field and Hemisphere \[F(1,19) = 9.17, p = .007\], while an ANOVA for bilateral presentations revealed a significant 3-way interaction between Visual field of the word, Lateral site, and Hemisphere \[F(2,38) = 6.50, p = .008\]. These interactions are captured in Figures 3.26 and 3.27, respectively.
Interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere for mean amplitudes of the posterior N1 component at lateral sites for a lateralized Stroop task with delayed matching response (numbers in figure represent p values for pairwise comparisons of means)

A) Unilateral presentations

B) Bilateral presentations
Posterior P1/N1 Complex - Peak Latencies

Peak latency measurements of the P1 and N1 components at the temporal, parietal and occipital sites over both hemispheres for LVF and RVF unilateral presentations as well as the difference between ipsilateral and contralateral peak latencies, also referred to as Interhemispheric Transfer Time (IHTT), are presented in Tables 3.3 and 3.4. Latency shifts for the earlier P1 component were between 39 and 46 msec, while the latency shifts for the N1 component were between 8 and 33 msec. Inspection of the IHTTs for only the N1 indicated that there was marked differences between the two hemispheres: the IHTTs from the RH to the LH range between 6 and 15 msec, while the IHTTs from the LH to the RH range between 23 and 33 msec. Contralateral projections to the temporal sites over

Table 3.3

Peak latencies (msec) of the posterior P1 component for temporal, parietal and occipital sites for unilateral lateralized Stroop presentations with delayed matching response over both hemispheres (IHTT signifies Inter-Hemispheric Transfer Time)

<table>
<thead>
<tr>
<th>Site</th>
<th>LH</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ipsilateral</td>
<td>Contralateral</td>
</tr>
<tr>
<td>Temporal</td>
<td>135</td>
<td>96</td>
</tr>
<tr>
<td>Parietal</td>
<td>134</td>
<td>95</td>
</tr>
<tr>
<td>Occipital</td>
<td>138</td>
<td>92</td>
</tr>
</tbody>
</table>

* indicates missing data, because peaks were not well defined
Table 3.4

Peak latencies (msec) of the posterior N1 component for temporal, parietal and occipital sites for unilateral lateralized Stroop presentations with delayed matching response over both hemispheres (IHTT signifies Inter-Hemispheric Transfer Time)

<table>
<thead>
<tr>
<th>Site</th>
<th>LH</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ipsilateral</td>
<td>Contralateral</td>
</tr>
<tr>
<td>Temporal</td>
<td>176</td>
<td>168</td>
</tr>
<tr>
<td>Parietal</td>
<td>170</td>
<td>155</td>
</tr>
<tr>
<td>Occipital</td>
<td>179</td>
<td>171</td>
</tr>
</tbody>
</table>

both hemispheres generated earlier peak amplitudes for P1 and N1 components than ipsilateral projections, as shown in Figure 3.28.

N2 Component: Mean Amplitude Between 220 and 300 msec

Vertex sites. For vertex sites (i.e., Fz, Cz, Pz, and Oz) ANOVAs did not reveal any statistically significant effects for the all trial analyses or for separate unilateral and bilateral analyses.

Lateral sites. An ANOVA showed a statistically significant main effect for Condition \[E(1,19) = 9.67, \ p = .006\], with the incongruent condition generating larger N2 amplitudes (1.85 uV) than the congruent condition (2.25 uV). There was also a significant 3-way interaction between Sex, Lateral site, and Hemisphere \[E(4,76) = 4.23, \]
Post-hoc analyses showed that only males generated more negative amplitudes over the RH than over the LH at the temporal and parietal sites.

Figure 3.28

ERPs waveforms for left (T5) and right (T6) temporal sites during unilateral LVF and RVF presentations of Stroop stimuli with delayed matching response. Note the latency and amplitude differences for the P1 and N1 components between contralateral and ipsilateral VF-hemisphere conditions.

Additional ANOVAs for unilateral and bilateral trials revealed the same significant 3-way interaction between Sex, Lateral site, and Hemisphere \( F(4,76) = 4.26, p = .01 \) and \( F(4,76) = 3.73, p = .01 \), respectively]. These two interactions are similar to the interaction for all trials (see Figure 3.29).
P3 Component - Mean Amplitude Between 300 and 500 msec

**Vertex sites.** An ANOVA for vertex sites showed a statistically significant main effect for Condition \([F(1,19) = 12.24, p = .002]\), with larger P3 amplitudes for congruent trails (4.40 uV) than for incongruent trails (3.65 uV). There was also a significant main effect of Vertex site \([F(3,57) = 10.35, p = .0008]\). Post-hoc analyses indicated that the mean P3 amplitude at the parietal site (5.66 uV) was significantly greater than the mean P3 amplitude at the frontal site (2.60 uV), while central (3.42 uV) and occipital (4.42 uV) mean amplitudes were intermediate and did not significantly differ from those of the

Figure 3.29

Interaction between Sex, Lateral site, and Hemisphere for mean amplitudes of N2 component at lateral sites for a lateralized Stroop task with delayed matching response (numbers in figure represent p values for pairwise comparisons of means)
other sites. A similar pattern of mean amplitudes across vertex sites was found for unilateral trials \( F(3, 57) = 10.83, p = .0007 \) as well as for bilateral trials \( F(3, 57) = 9.60, p = .001 \).

**Lateral sites.** For lateral sites, the ANOVA showed a statistically significant 2-way interaction between Visual field of the word and Hemisphere \( F(1, 19) = 19.78, p = .0003 \), a 3-way interaction between Visual field of the word, Lateral sites, and Hemisphere \( F(4, 76) = 11.51, p < .0001 \), and a 4-way interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere \( F(4, 76) = 4.97, p = .01 \). Only the two four-way interaction will be discussed since the lower order interactions can be explained by the higher order interactions.

The interaction between Presentation, Visual field of the word, Lateral sites, and Hemisphere is presented in Figure 3.30 for unilateral and bilateral presentations, respectively. For unilateral trials, post-hoc analyses indicated that P3 amplitudes over the LH were larger for ipsilateral (LVF) than for contralateral (RVF) presentations over all sites, while over the RH the LVF presentations (i.e., contralateral projections) generated larger P3 amplitudes than RVF presentations (i.e., ipsilateral projections) over the frontal and central sites. For bilateral trials, LVF-word/RVF-color presentations generated larger P3 amplitudes only over the RH temporal site. These findings were also supported for unilateral, but not bilateral, presentations as indicated by a significant 2-way interaction between Visual field and Hemisphere \( F(1.19) = 16.10, p = .0007 \).
Figure 3.30

Interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere for P3 amplitudes at lateral sites for a lateralized Stroop task with delayed matching response (numbers in figure represent p values for pairwise comparisons of means)

A) Unilateral presentations

B) Bilateral presentations
Separate ANOVAs for unilateral and bilateral trials also revealed a significant main effects for Condition, \(F(4,76) = 5.22, p = .005\) and \(F(4,43) = 4.43, p = .01\), respectively. For unilateral presentations there was also a significant 3-way interaction between Presentation, Visual field, and Lateral site \(F(4,76) = 10.92, p < .0001\). These findings were similar to those reported for the all trials at the vertex sites and will not be further analyzed.

**P3 Component - Peak Amplitudes and Latencies**

Additional ANOVAs were performed for the P3 component peak amplitudes and peak latencies as dependent measures. Peak amplitudes yielded similar findings as analyses with mean amplitudes: there was a significant main effect of Condition \(F(1,19) = 11.37, p = .003\), a significant main effect of Lateral site \(F(4,76) = 8.47, p = .001\), a 2-way interaction between Visual field of the word and Hemisphere \(F(1,19) = 11.55, p = .003\), a 3-way interaction between Presentation, Visual field of the word, and Hemisphere \(F(1,19) = 8.85, p = .008\), a 3-way interaction between Visual field of the word, Lateral site, and Hemisphere \(F(4,76) = 5.95, p = .003\), and a 4-way interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere \(F(4,76) = 5.59, p = .003\). These findings parallel those described with mean amplitudes (see Figure 3.30) and will not be further analyzed.

Separate analyses of P3 peak amplitudes for unilateral trials revealed a significant main effect for Lateral site \(F(4,76) = 7.82, p < .0001\), a significant interaction between Visual field and Hemisphere \(F(1,19) = 19.84, p = .0002\), and significant 3-way interaction between Visual field, Lateral site, and Hemisphere \(F(4,76) = 9.47, p = .003\).
An ANOVA for bilateral trials only revealed a significant main effect for Lateral site [F(4, 76) = 8.77, p = .0009]. All these findings were similar to those for mean amplitudes and therefore will not be further analyzed.

Figure 3.31

Interaction between Sex, Visual field of the word, and Hemisphere of P3 peak latencies at lateral sites for a lateralized Stroop task with delayed matching response (numbers in figure represent p values for pairwise comparisons of means)

Analyses of P3 peak latencies for all trials and for unilateral and bilateral presentations revealed only one statistically significant finding. For unilateral presentations, there was a significant 3-way interaction between Sex, Visual field, and Hemisphere [F(1, 19) = 8.31, p = .01], as shown in Figure 3.31. Post-hoc analyses indicated that P3 latencies for males occurred significantly earlier over the LH for the
RVF presentations (i.e., direct projection) than for LVF presentations (i.e., crossed projections).

**Summary**

**N1/P1 anterior complex.** Results for the exogenous N1/P1 complex showed that males generated more negative amplitudes than females.

**P1/N1 posterior complex.** Posterior P1/N1 complex indicated early laterality effects such that the direct unilateral projections generated more negative amplitudes and occurred earlier (see Figures 3.26, 3.27 A, and 3.28). Separate analyses of posterior N1 peak amplitudes showed that unilateral contralateral projections generated more negative peak amplitudes at the temporal sites over both hemispheres and at the parietal site only over the RH (see Figure 3.27 A). For bilateral presentations, however, only the LVF-word/RVF-color trials generated greater N1 amplitudes and only over the LH temporal site. Early laterality effects were also noticed for peak latencies of the posterior P1 and N1 components: both posterior components showed marked latency shifts between ipsilateral and contralateral unilateral presentations such that there was on average an IHTT of approximately 41 msec for P1 peaks and of approximately 20 msec for N1 peak (see Tables 3.3 and 3.4). There was also marked hemispheric asymmetry with respect to the IHTT for the N1 component: average IHTT from the RH to the LH was approximately 10 msec, while average IHTT from the LH to the RH was approximately 28 msec (see Table 3.4). With respect to hemispheric asymmetries, bilateral LVF-color/RVF-word trials generated more negative amplitudes than LVF-word/RVF-color trials only at the LH temporal site (see Figure 3.27 B).
**N2 component.** The SE was first observed for the N2 component such that the congruent condition generated larger N2 amplitudes than the incongruent condition. In addition, males generated larger N2 amplitudes over the RH than over the LH at temporal and parietal sites (see Figure 3.29).

**P3 component.** Analyses of mean and peak amplitudes indicated that there were greater P3 amplitudes for congruent than for incongruent presentations. The P3 amplitudes were highest at the parietal sites and lowest at the frontal sites. P3 latencies occurred significantly earlier for males for unilateral RVF than for LVF presentations over the LH. Other findings for the P3 component were related to VF-hemisphere manipulations: LVF unilateral trials generated greater amplitudes than RVF unilateral trials over the ipsilateral hemisphere (i.e., indirect projections) at all sites and only at the frontal and central sites at the contralateral hemisphere (i.e., direct projections). For bilateral presentations, only LVF-word/RVF-color trials generated more positive amplitudes than LVF-color/RVF-word trials over the RH parietal site (see Figure 3.30 B).

**Discussion**

**Behavioral Data**

Delayed matching responses to lateralized presentations of Stroop stimuli were primarily used to investigate the potential overlap of P3 and N4 ERP components and no behavioral SE was expected. Unexpectedly, the results showed a SE even when the target was delayed 700 msec after the presentations of the Stroop stimulus. RTs were approximately 14 msec longer for incongruent than congruent presentations, which indicates that there was a persistence of the Stroop stimuli memory trace that lasted until
the target presentations. This finding contradicts the relative speed of processing model prediction. On the other hand, the automaticity model does not provide enough evidence to make sound predictions for delayed matching response of lateralized Stroop stimuli. In fact, Shiffrin (1996) stated that "we really know little about the memorial fate of unattended stimuli, whether tested implicitly or explicitly." (p. 63). Anyhow, any comprehensive model of the SE should account for the persistence of the memory trace of Stroop stimuli which generates interference at least 700 msec after stimulus presentation.

The only finding related to hemispheric asymmetries was that the overall processing of bilateral presentations with 'different' targets was faster when the word was initially projected to the language dominant LH and the color to the RH than the reverse projections. This finding may suggest strategy differences depending on which hemisphere first receives the word versus the color, regardless of the congruency condition. Sex differences also emerged in the second experiment: males showed an equivalent SE for 'same' and 'different' trials, while females showed a SE only for 'different' trials. These findings suggest that males and females differ either in brain organization or in performance strategies. Lateralized presentation of the Stroop task with delayed matching response indicated practice effects which did not affect the SE. There was an improvement of RTs for the LVF-word trials such that only 'same' trials improved with practice. The findings related to practice effects were different from the findings of Experiment 1 and provided no additional evidence for sound conclusions about practice effects. Hopefully, the remaining two experiments will provide more information to disentangle the question whether practice effects are spurious or real.
ERP Data

Early laterality effects - direct versus indirect anatomical pathways. For the lateralized Stroop task with delayed matching response, the early laterality effects due to VF-hemisphere manipulations were found only for unilateral presentations at the posterior P1/N1 complex. Contralateral projections generated earlier and greater peak amplitudes than ipsilateral projections for the P1 and subsequent N1 components, due to the shorter anatomical pathways for contralateral than ipsilateral projections (see Figure 3.26 and Figure 3.28). However, there were hemispheric differences for the posterior N1: the LH showed early effects only over temporal site, while the RH showed VF-hemisphere manipulation at the temporal and parietal sites (see Figure 3.27 A). These hemispheric asymmetries of early effects will be further analyzed in the next section.

Also in Experiment 2, the IHTT was greater for the earlier P1 component (i.e., 39 - 46 msec) than for the subsequent N1 component (i.e., 8 - 29 msec) (see Table 3.3 and Table 3.4). The difference in IHTT between the P1 and N1 components may indicate involvement of different callosal channels with different conduction velocities in interhemispheric transfer. In addition, for the posterior N1 component there was marked hemispheric asymmetry for IHTT. The results clearly showed that transfer of information from the RH to the LH was much faster (i.e., 8 - 15 msec) than from the LH to the RH (i.e., 23 - 33 msec) (see Table 3.4). This finding is contrary to the IHTT results in Experiment 1, where posterior hemispheric asymmetries for interhemispheric information transfer were missing. This finding suggests that the transfer of the visual information may depend on task requirements, in other words, upon top-down
processing. It appears that in the case of maintenance of the stimulus representation (i.e., delayed matching response), the LH obtained the information from the opposite hemisphere faster than the RH. Consistent with findings for the lateral Stroop task, late laterality effects were also observed with the delayed matching responses to the lateralized Stroop stimuli. Late laterality effects were primarily observed for unilateral presentations over the LH, with ipsilateral presentations paradoxically generating greater P3 amplitudes than contralateral presentations. At the anterior sites over the RH, however, contralateral presentations generated greater amplitudes than ipsilateral presentations. Contrary to the late laterality effects for the lateralized Stroop task, where late laterality effects showed greater amplitudes for indirect than for direct projections, the late laterality effects changed with delayed matching responses: only LVF presentations generated greater amplitudes across all the LH sites (i.e., indirect projections) and over the anterior part of the RH (i.e., direct projections) (see Figure 3.30 A). In addition, for bilateral presentations, there were greater amplitudes at the RH temporal site for LVF-word/RVF-color trials than for LVF-word/RVF-color trials (see Figure 3.30 B). These findings suggest that the P3 amplitudes were sensitive to initial word presentations from the LVF in unilateral as well as in bilateral trials. In addition, these findings partially disconfirm the assertion from Experiment 1 that the greater P3 amplitudes for ipsilateral than for contralateral presentations were due to the carry-over effects from the preceding N1 component. If larger P3 amplitudes are associated with the preceding smaller N1 amplitude, then that pattern was observed across all the LH but only over anterior sites over the RH (see Figure 3.30 A and Figure 3.28).
Laterality effects - hemispheric specialization. The first evidence for hemispheric specialization was apparent for the early posterior N1 component. However, this is contained within a rather complex 4-way interaction. One component of this parallels findings from Experiment 1: for bilateral presentations, VF effects were present over LH, but not over RH temporal sites, and this took form of more negative amplitudes for direct word-VF than indirect word-VF presentations (see Figure 3.27 B). The differences between direct and indirect projections at the temporal site over the LH may not be due to only VF-hemisphere manipulations but also due to the greater LH involvement in language processing. These findings parallel those of Experiment 1 and thus give greater credibility to early effects of hemispheric specialization.

SE. The main assumption for Experiment 2 was that there would be an additional N4 component, which was missing in Experiment 1 because of the overlap with the P3 component. The results clearly indicated that there was no visible N4 component in the lateralized Stroop task with delayed matching responses, suggesting that the lateralized Stroop task does not produce an N4 component. The results also suggest that the Stroop-like interference does not produce an N4 component in the same way as other lexical decision or semantic incongruency tasks. However, in Experiment 2 the effects of the lateralized Stroop paradigm were observed, first at the N2 component and followed by the endogenous P3 component. As in Experiment 1, the congruent condition generated greater P3 amplitudes than the incongruent condition. Consistent with Experiment 1, the SE findings can be explained by the same ease of processing model. Surprisingly, the SE did not show any changes due to the VF-hemisphere effects. The lack of VF-hemisphere
effects on P3 amplitudes for Experiment 2 indicates that hemispheric asymmetries for the P3 found in Experiment 1 depend upon making an immediate response to the lateralized Stroop stimuli (e.g., top-down control of processing). The next two experiments will further examine whether there are hemispheric asymmetries for SE that depend upon the cognitive nature of the task.

In order to further investigate hemispheric asymmetries with lateralized stimuli that generate interference effects, a new face/word Stroop analog task was developed. The leading idea in developing this new Stroop analog task was to combine two stimuli with opposite hemispheric superiority. Since one component of the Stroop analog is usually a word associated with LH superiority, an optimal choice for the second component is faces, which is presumably better processed in the RH. Consequently, for the Experiment 3 lateralized presentations of face/word Stroop analog stimuli were used, and participants identified faces and ignored the face related words. It was expected that there would be a greater SE for unilateral RVF presentations than for LVF presentations due to the LH superiority for word processing. Electrophysiologically, we expect to replicate the findings from Experiment 1 with respect to early laterality effects due to the differences between direct and indirect anatomical pathways, as well as the laterality effect due to hemispheric specialization effects with words. We also expect to obtain a similar pattern of ERP components for the SE for the lateralized face/word Stroop analog task as for the lateralized Stroop task. The novel aspect of this task is that a RH superiority is expected for face processing.
EXPERIMENT 3: LATERALIZED FACE/WORD STROOP ANALOG

TASK - FACE TARGET

Behavioral Data

Reaction times were entered into a 2x2x2x2 factorial ANOVA, with Sex (male, female) as a between-subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the Word (left visual field - LVF, right visual field - RVF), and Block (block 1, block 2) as within subjects factors. All post-hoc analyses were carried out using the Tukey honestly significant difference (HSD) test.

The analysis of RTs revealed a significant main effect of Condition \([F(1,18) = 34.27, p < .00005]\) with faster RTs for congruent trials \((M = 642 \text{ msec})\) than for incongruent trials \((M = 672 \text{ msec})\). There was also a statistically significant main effect of Block \([F(1,18) = 12.42, p = .002]\) indicating a practice effect whereby RTs were faster in the second block \((M = 643 \text{ msec})\) than in the first block \((M = 672 \text{ msec})\).

The ANOVA also revealed several statistically significant 2-way interactions: Condition and Presentation \([F(1,18) = 4.48, p < .05]\), Presentation and Visual field of the word \([F(1,18) = 9.25, p = .007]\), and between Sex and Block \([F(1,18) = 6.35, p = .01]\).

There was also statistically significant 3-way interaction between Condition, Presentation, and Block \([F(1,18) = 5.52, p = .03]\).

The interaction between Sex and Block is presented in Figure 3.32. Post-hoc analyses showed that females but not males improved their overall RTs with practice.
Figure 3.32

Interaction between Sex and Block for a lateralized Face/Word Stroop analog - face target task (numbers in the figure represent p-values for comparisons between pairwise means).

The interaction between Visual field of the word and Presentation is presented in Figure 3.33. Post-hoc analyses revealed that unilateral presentations had equivalent RTs regardless of the VF of the word whereas for bilateral presentations the LVF-word/RVF-face trials were significantly faster than LVF-face/RVF-word trials.

The interaction between Condition and Presentation is shown in Figure 3.34. Post-hoc analyses revealed that there was greater SE for bilateral than for unilateral presentations.
Figure 3.33

Interaction between Presentation and Visual field of the word for a lateralized Face/Word Stroop analog - face target task (numbers in the figure represent p-values for comparisons between pairwise means)

The 3-way interaction between Condition, Presentation and Block is presented in Figure 3.35, albeit simplified with the Incongruent - Congruent difference scores. Post-hoc analyses showed that in the first block bilateral presentations produced a significantly greater SE than unilateral presentations, but with practice both presentations showed an equal SE.

Additional ANOVAs (4-way) were performed separately for unilateral and bilateral trials to further tease apart Visual field effects. For unilateral trials, the levels of the Visual field factor are LVF and RVF, while for bilateral trials the levels are LVF-word/RVF-face and RVF-word/LVF-face. Since several of the significant effects parallel
that of the 5-way analyses, only novel findings involving the Visual field factor will be presented.

The ANOVA for unilateral trials revealed significant 4-way interaction between Sex, Condition, Visual field, and Block \( [F(1,18) = 4.69, \ p = .04] \). However, post-hoc analyses indicated that none of the pairwise means were statistically significant different.

The ANOVA for bilateral trials revealed a significant main effect of Visual field of the Word \( [F(1,18) = 8.31, \ p = .01] \) as shown in Figure 3.33. There was also a statistically significant interaction between Condition and Visual field of the word \( [F(1,18) = 5.50, \ p = .03] \), as presented in Figure 3.36. A post-hoc analysis indicated that there was a greater SE for RVF-word/LVF-face than for LVF-word/RVF-face trials.
Figure 3.35

Interaction between Condition, Presentation and Block for a lateralized Face/Word
Stroop analog - facet target task, using Incongruent - Congruent difference scores as a
dependent measure (numbers in the figure represent p-values for comparisons between
pairwise means)

In summary, the results indicated that there was an interference effect in the order
of 30 msec, meaning that overall RTs were faster for congruent than for incongruent
trials. Furthermore, there was a greater SE for bilateral than for unilateral presentations
(see Figure 3.34). This task also showed a practice effect, at least for females.
Additionally, with practice there was a trend for the interference effect to decrease for
bilateral presentations, but to increase for unilateral trials. With respect to hemispheric
asymmetries, results did not indicate RH superiority for face identification for this task.
However, hemispheric asymmetries occurred but only for the bilateral presentations:
there was a greater SE when the word was presented to the language dominant LH and
the face to the face dominant RH than vice versa. In other words, there was less interference when the target face was presented to the LH and the distractor word was presented to the RH, as shown in Figure 3.36.

Figure 3.36

Interaction between Condition and Visual field of the Word for bilateral presentations in a lateralized Face-Stroop task (numbers in the figure represent p-values for comparisons between pairwise means)
ERP Data

Typical ERPs waveforms for the lateralized Face/Word Stroop analog task - face target are presented in Figure 3.37. Several components were identified: anterior N1/P1 complex, posterior P1/N1 complex, N2, and P3 component.

For each complex and component two principal analyses were performed, one for vertex sites and one for lateral sites. For vertex sites, mean amplitudes were entered into a 2x2x2x2x4 mixed factorial ANOVA with Sex (males, females) as a between subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (LVF, RVF), and Vertex site (Fz, Cz, Pz, and Oz) as within subject factors. Lateral sites had a similar design except that the vertex site variable was replaced by two other variables: Lateral site [frontal (F3/F4), central (C3/C4), temporal (T5/T6), parietal (P3/P4), and occipital (O1/O2)], and Hemisphere [left hemisphere (LH), right hemisphere (RH)].

Anterior N1/P1 Complex - Mean Amplitude Between 100 and 220 msec

Vertex sites. For vertex sites (i.e., Fz and Cz) an ANOVA revealed a statistically significant main effect of Condition \[F(1,18) = 7.50, \ p = .01\] with the incongruent condition generating more negative amplitudes (.70 uV) than the congruent condition (1.15 uV). There was also a statistical significant main effect of Visual field of the word \[F(1,18) = 8.76, \ p = .008\] with more negative amplitudes for LVF presentations (.67 uV) than for RVF presentations (1.18 uV). There was also a statistically significant 3-way interaction between Presentation, Visual field of the word, and Vertex site \[F(1,18) =\]
Figure 3.37

ERP waveforms for congruent and incongruent presentations in a lateralized face/word Stroop analog - face target task

- - Congruent

--- Incongruent
9.47, \( p = .006 \)], and a 5-way interaction between Sex, Condition, Presentation, Visual field of the word, and Vertex site \( F(1,18) = 15.49, p = .001 \).

The interaction between Presentation, Visual field of the word, and Vertex site is presented in Figure 3.38. Post-hoc analyses indicated that for unilateral presentations, LVF trials evoked more negative amplitudes than RVF trials. In addition, unilateral RVF trials evoked more negative amplitudes over the frontal site than over the central site.

Additional analyses for just unilateral trials revealed a significant main effect of Visual field \( F(1,18) = 7.08, p = .01 \), a significant 2-way interaction between Visual field and Vertex site \( F(1,18) = 11.29, p = .003 \), and a significant 4-way interaction between Sex, Condition, Visual field, and Vertex site \( F(1,18) = 9.88, p = .006 \). Results for unilateral trials parallel those for all trials and will not be further discussed. For just bilateral trials, there was only a statistically significant 3-way interaction between Sex, Visual field of the word, and Vertex site \( F(1,18) = 8.79, p = .009 \), as shown in Figure 3.39. Post-hoc analyses revealed that at the central (Cz) site males generated more negative amplitudes for the LVF trials than for RVF trials.

**Lateral sites.** For lateral sites (i.e., F3, F4, C3, and C4) an ANOVA revealed a significant main effect of Condition \( F(1,18) = 6.90, p = .01 \) with the incongruent condition generating more negative amplitudes (63 uV) than the congruent condition (1.01 uV). There was also a statistically significant 3-way interaction between Condition, Presentation, and Lateral site \( F(1,18) = 12.07, p = .003 \), a 3-way interaction between Presentation, Visual field of the word, and Hemisphere \( F(1,18) = 9.02, p = .008 \), and
Interaction between Presentation, Visual field of the word, and Vertex site for mean amplitudes of the anterior N1/P1 complex at vertex sites for a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p values for pairwise comparisons of means)

5-way interaction between Sex, Presentation, Visual field of the word, Lateral site, and Hemisphere \( F(1,18) = 8.62, p = .009 \).

The interaction between Condition, Presentation, and Lateral site is presented in Figure 3.40. Post-hoc analyses indicated a tendency for more positive amplitudes for congruent than for incongruent condition (i.e., Stroop effect) over frontal and especially central sites for unilateral presentations, but only over frontal sites for bilateral presentations. As shown in Figure 3.40, at the frontal sites, there was a tendency for a greater SE for bilateral than for unilateral presentations. However, simple interaction
Figure 3.39

Interaction between Sex, Visual field of the word, and Vertex site for mean amplitudes of the anterior N1/P1 complex at vertex sites for bilateral presentations in a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p values for pairwise comparisons of means)

Contrasts indicated that there was no significant interaction between unilateral and bilateral presentations at the frontal site. At the central site, however, there was a SE only for unilateral, but not for bilateral, presentations.

The interaction between Presentation, Visual field of the word, and Hemisphere is presented in Figure 3.41. Post-hoc analyses indicated that for unilateral presentations the LVF trials evoked more negative amplitudes than RVF trials over both hemispheres. For bilateral presentations, however, the LVF-word/RVF-face trials evoked more negative mean amplitudes than LVF-face/RVF-word trials only over the LH.
Interaction between Condition, Presentation, and Lateral site for mean amplitudes of the anterior N1/P1 complex at lateral sites for a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p values for pairwise comparisons of means).

An additional ANOVA of lateral sites for just unilateral trials revealed a significant 2-way interaction between Condition and Lateral site \( F(1,18) = 8.51, p = .009 \), a 2-way interaction between Visual field and Lateral site \( F(1,18) = 8.31, p = .01 \), a 3-way interaction between Visual field, Lateral site, and Hemisphere \( F(1,18) = 7.43, p = .01 \), a 4-way interaction between Sex, Condition, Visual field, and Lateral site \( F(1,18) = 9.50, p = .006 \), and a 4-way interaction between Sex, Visual field, Lateral site, and Hemisphere \( F(1,18) = 9.78, p = .006 \). Results from the 2-way and 3-way interactions parallel those found for all trials (see Figure 3.40 and 3.41). Once again, higher-order interactions that include sex will not be further analyzed.
An ANOVA for bilateral presentations revealed a significant 2-way interaction between Visual field of the word and Hemisphere \( [F(1,18) = 13.79, p = .002] \) and 5-way interaction between Sex, Condition, Visual field of the word, Lateral site, and Hemisphere \( [E(1,18) = 10.41, p = .005] \). The interaction between Visual field of the word and Hemisphere is contained within the interaction found for all trials (see Figure 3.41) and will not be further analyzed.

**Posterior P1/N1 Complex - Mean Amplitude Between 90 and 220 msec**

**Vertex sites.** For the vertex sites (i.e., Pz and Oz) an ANOVA revealed a significant 2-way interaction between Presentation and Visual field of the word \( [F(1,18) = 13.23, p = \]
The interaction between Condition and Vertex site is presented in Figure 3.42. Post-hoc analyses indicated that LVF unilateral presentations evoked significantly more negative amplitudes than unilateral RVF presentations.

The interaction between Condition and Vertex site is presented in Figure 3.43. Post-hoc analyses revealed that there were more negative amplitudes for incongruent than for congruent trials (i.e., SE), and this difference was larger over the parietal than over the occipital sites.

The interaction between Visual field of the word and Vertex site is presented in Figure 3.44. Post-hoc analyses indicated that LVF-word presentations evoked more negative amplitudes than RVF-word presentations over the parietal, but not occipital, site.

The ANOVA for just unilateral presentations showed a significant main effect for Condition \([F(1,18) = 7.51, p = .01]\) with more negative mean amplitudes for incongruent (.47 uV) than for congruent trials (1.13 uV). There was also a significant main effect for Visual field \([F(1,18) = 15.61, p = .0009]\) indicating that LVF presentations generated more negative mean amplitudes (.47 uV) than RVF presentations (1.42 uV). For bilateral presentations, the ANOVA revealed a significant interaction between Visual field of the word and Vertex site \([F(1,18) = 17.77, p = .0005]\) similar to that for the all trials analysis (see Figure 3.44).
Figure 3.42

Interaction between Presentation and Visual field of the word for mean amplitudes of the posterior P1/N1 complex at vertex sites for a lateralized Face/word Stroop analog - face target task (numbers in figure represent p-values for pairwise comparisons of means)

Figure 3.43

Interaction between Condition and Vertex site for mean amplitudes of the posterior P1/N1 complex at vertex sites for a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p-values for pairwise comparisons of means)
Figure 3.44

Interaction between Visual field of the word and Vertex site for mean amplitudes of the posterior P1/N1 complex at vertex sites for a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p-values for pairwise comparisons of means)

Lateral sites. For the lateral sites (i.e., T5, T6, P3, P4, O1, and O2) an ANOVA revealed a significant main effect for Lateral site \( F(2.36) = 11.03, p = .0002 \). Post-hoc analyses showed that temporal (-.73 uV) sites were significantly more negative than occipital sites (.11 uV) and parietal sites (.61 uV). There was also a statistically significant main effect of Hemisphere \( F(1,18) = 15.56, p = .0007 \), with the LH showing more negative mean amplitudes (-.44 uV) than the RH (.43 uV). There was also a statistically significant 2-way interaction between Presentation and Visual field of the word \( F(1,18) = 9.46, p = .007 \), a 2-way interaction between Lateral site and Hemisphere
\[ F(2,36) = 14.66, p = .001 \], a 2-way interaction between Visual field of the word and Lateral site \[ F(2,36) = 5.56, p = .01 \], a 3-way interaction between Presentation, Visual field of the word, and Hemisphere \[ F(1,18) = 7.18, p = .01 \], a 3-way interaction between Presentation, Visual field of the word, and Lateral site \[ F(2,36) = 8.36, p = .001 \], a 4-way interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere \[ F(2,36) = 16.86, p = .0001 \], a 5-way interaction between Sex, Condition, Presentation, Visual field of the word, and Hemisphere \[ F(1,18) = 11.34, p = .003 \], and a 5-way interaction between Sex, Presentation, Visual field of the word, Lateral site, and Hemisphere \[ F(2,36) = 4.91, p = .01 \]. Only the 4-way interaction will be further analyzed since lower level interactions (i.e., 2-way and 3-way interactions) are captured in the 4-way interaction.

The interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere is presented in Figure 3.45. Post hoc analyses revealed that, for unilateral presentations, LVF trials generated more negative mean amplitudes than RVF trials across all the posterior regions of the RH, but only over the parietal and occipital sites (i.e., not the temporal sites) over the LH. For bilateral trials, however, the LVF-face/RVF-word trials generated more negative amplitudes than the LVF-word/RVF-face trials at the occipital sites over both hemispheres and at the temporal sites over the RH.
Figure 3.45

Interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere for mean amplitudes of the posterior P1/N1 complex at lateral sites for a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p-values for pairwise comparisons of means)

A) Unilateral presentations

B) Bilateral presentations
An ANOVA for posterior P1/N1 mean amplitudes for unilateral trials revealed a significant main effect for Visual field \([F(1,18) = 11.80, \ p = .003]\), Lateral site \([F(2,36) = 11.70, \ p = .0004]\), and for Hemisphere \([F(1,18) = 14.83, \ p = .001]\). Main effects for Lateral site and Hemisphere parallel the all trials results, while Visual field results showed that the LVF presentations generated more negative amplitudes (-.43 uV) than the RVF presentations (.51 uV). There was also a significant 2-way interaction between Visual field and Hemisphere \([F(1,18) = 10.57, \ p = .004]\), a 2-way interaction between Lateral site and Hemisphere \([F(2,36) = 12.47, \ p = .001]\), and a 3-way interaction between Visual field, Lateral site, and Hemisphere \([F(2,36) = 11.86, \ p = .0002]\), as can be seen in Figure 3.45 A. There was also a significant 4-way interaction between Sex, Condition, Visual field, and Hemisphere \([F(2,36) = 14.33, \ p = .001]\), which will not be further analyzed.

For bilateral presentations, the ANOVA showed a statistically significant main effect of Lateral site \([F(2,36) = 12.47, \ p = .0002]\), and a main effect for Hemisphere \([F(1,18) = 14.92, \ p = .001]\), consistent with the all trials analysis. There was also a significant 2-way interaction between Visual field of the word and Lateral site \([F(2,36) = 14.71, \ p = .0002]\), a 2-way interaction between Lateral site and Hemisphere \([F(2,36) = 15.99, \ p = .0002]\), and 3-way interaction between Visual field of the word, Lateral site, and Hemisphere \([F(2,36) = 9.58, \ p = .001]\), which is already presented in Figure 3.45 B. There was also a significant 4-way interaction between Sex, Visual field of the word, Lateral site, and Hemisphere \([F(2,36) = 6.09, \ p = .007]\), which will not be further analyzed.
Posterior P1/N1 Complex - Positive Peak Amplitudes

An ANOVA for positive peak amplitudes revealed a significant main effect for Hemisphere \([F(1,18) = 27.05, p < .0001]\), a 2-way interaction between Presentation and Visual field of the word \([F(1,18) = 12.98, p = .002]\), and a 2-way interaction between Lateral site and Hemisphere \([F(2,36) = 14.26, p = .0002]\). These findings are consistent with the mean amplitude analyses.

An ANOVA for posterior P1/N1 positive peak amplitudes for unilateral trials revealed a significant main effect for Visual field \([F(1,18) = 13.51, p = .002]\), a main effect for Hemisphere \([F(1,18) = 29.15, p < .0001]\), and 2-way interaction between Lateral site and Hemisphere \([F(2,36) = 9.61, p = .005]\). Additional analyses for bilateral presentations revealed a significant main effect for Hemisphere \([F(1,18) = 22.65, p = .0002]\), a significant 2-way interaction between Lateral site and Hemisphere \([F(2,36) = 18.28, p = .0008]\), and 4-way interaction between Sex, Visual field of the word, Lateral site, and Hemisphere \([F(2,36) = 6.98, p = .01]\). All these findings parallel those found with mean amplitudes.

Posterior P1/N1 Complex - Negative Peak Amplitudes

An ANOVA for negative peak amplitudes revealed a significant main effect of Lateral site \([F(2,36) = 18.61, p < .0001]\), which is equivalent to that found with mean amplitudes. There was also a statistically significant 3-way interaction between Presentation, Visual field of the word, and Hemisphere \([F(2,18) = 7.98, p = .01]\), and a 4-way interactions between Presentation, Visual field of the word, Lateral site and
Hemisphere \(F(2,36) = 8.03, \ p = .01\), which parallels that of mean amplitudes as shown in Figure 3.45.

Additional analyses for unilateral presentations revealed a statistically significant main effect for Condition \(F(1,18) = 8.78, \ p = .008\), with incongruent trials generating more negative amplitudes (-4.74 uV) than the congruent trials (-4.06 uV). There was also a significant main effect for Lateral site \(F(2,36) = 18.92, \ p < .0001\), a significant 2-way interaction between Visual field and Hemisphere \(F(1,18) = 8.53, \ p = .009\), and a 3-way interaction between Visual field, Lateral site, and Hemisphere \(F(2,36) = 9.51, \ p = .008\). These effects are equivalent to those found with mean amplitudes. An ANOVA for bilateral presentations showed only a statistically significant main effect for Lateral site \(F(2,36) = 16.84, \ p < .0001\), also equivalent to that found in analyses with mean amplitudes.

**Posterior P1/N1 Complex - Peak Latencies**

Peak latency measurements of the P1 and N1 components at the temporal, parietal and occipital sites over both hemispheres for LVF and RVF unilateral presentations as well as the difference between ipsilateral and contralateral peak latencies [also referred to as Interhemispheric Transfer Time (IHTT)] are presented in Tables 3.5 and 3.6. Latency shifts for the P1 are between 13 and 37 msec, while the latency shifts for the subsequent N1 component are between 6 and 33 msec. Contralateral VF-hemisphere projections to the temporal sites over both hemispheres generated earlier peak amplitudes for P1 and N1 components than ipsilateral projections, as shown in Figure 3.46.
Table 3.5

Peak latencies (msec) of the posterior P1 component for temporal, parietal and occipital sites over both hemispheres in a lateralized Face/Word Stroop analog - face target task (IHTT signifies Inter-Hemispheric Transfer Time)

<table>
<thead>
<tr>
<th>Site</th>
<th>LH Ipsilateral</th>
<th>LH Contralateral</th>
<th>LH IHTT</th>
<th>RH Ipsilateral</th>
<th>RH Contralateral</th>
<th>RH IHTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal</td>
<td>128</td>
<td>99</td>
<td>29</td>
<td>132</td>
<td>114</td>
<td>18</td>
</tr>
<tr>
<td>Parietal</td>
<td>126</td>
<td>99</td>
<td>27</td>
<td>132</td>
<td>95</td>
<td>37</td>
</tr>
<tr>
<td>Occipital</td>
<td>129</td>
<td>98</td>
<td>31</td>
<td>138</td>
<td>125</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 3.6

Peak latencies (msec) of the posterior N1 component for temporal, parietal and occipital sites over both hemispheres in a lateralized Face/Word Stroop analog - face target task (IHTT signifies Inter-Hemispheric Transfer Time)

<table>
<thead>
<tr>
<th>Site</th>
<th>LH Ipsilateral</th>
<th>LH Contralateral</th>
<th>LH IHTT</th>
<th>RH Ipsilateral</th>
<th>RH Contralateral</th>
<th>RH IHTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal</td>
<td>183</td>
<td>168</td>
<td>15</td>
<td>183</td>
<td>165</td>
<td>18</td>
</tr>
<tr>
<td>Parietal</td>
<td>183</td>
<td>156</td>
<td>27</td>
<td>192</td>
<td>159</td>
<td>33</td>
</tr>
<tr>
<td>Occipital</td>
<td>183</td>
<td>177</td>
<td>6</td>
<td>192</td>
<td>171</td>
<td>21</td>
</tr>
</tbody>
</table>
Figure 3.46

ERP waveforms for left (T5) and right (T6) temporal sites during unilateral LVF and RVF presentations of face/word Stroop - face target stimuli. Note the latency and amplitude differences between contralateral and ipsilateral VF-hemisphere conditions.

N2 Component - Mean Amplitude Between 220 and 300 msec.

**Vertex sites.** No significant results were found at vertex sites.

**Lateral sites.** An ANOVA showed a statistically significant 2-way interaction between Lateral site and Hemisphere \( F(2,72) = 7.35, p = .002 \), a 3-way interaction between Presentation, Visual field of the word, and Hemisphere \( F(1,18) = 7.85, p = .01 \), and a 6-way interaction between Sex, Condition, Presentation, Visual field of the word,
Lateral site, and Hemisphere \([F(2,72) = 7.35, p = .002]\). The interaction between Lateral site and Hemisphere is presented in Figure 3.47. Post-hoc analyses indicated that over the temporal site the LH generated larger N2 amplitudes than the RH.

Figure 3.47

Interaction between Lateral site and Hemisphere for mean amplitudes of the N2 component at lateral sites in a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p-values for pairwise comparisons of means)

The interaction between Presentation, Visual field of the word, and Hemisphere is presented in Figure 3.48. Post-hoc analyses indicated that for unilateral presentations the RVF presentations generated significantly more negative amplitudes over the LH (i.e., direct projections) than over the RH (i.e., indirect projections). Conversely, for the
Interaction between Presentation, Visual field of the word, and Hemisphere for mean amplitudes of the N2 component at lateral sites in a lateralized Face/Word Stroop analog task (numbers in figure represent p-values for pairwise comparisons of means).

Bilateral presentations the LVF-word/RVF-face trials generated more negative amplitudes over the LH than over the RH. In other words, bilateral and unilateral presentations generated more negative amplitudes over the LH than over the RH when the face was presented directly to the LH (i.e., RVF).

An additional ANOVA for unilateral trials revealed only a significant 2-way interaction between Lateral site and Hemisphere \(F(4,72) = 7.07, p = .001\) equivalent to that in Figure 3.47. An ANOVA for bilateral trials revealed a significant 2-way interaction between Visual field of the word and Hemisphere \(F(1,18) = 9.61, p = .006\) as
seen in Figure 3.48, and a 2-way interaction between Lateral site and Hemisphere
\[ F(4,72) = 7.10, \ p = .004 \] with a similar pattern as that shown in Figure 3.47.

**P3 Component - Mean Amplitude Between 300 and 500 msec**

**Vertex sites.** An ANOVA for vertex sites showed a statistically significant main
effect for Vertex site \[ F(3,54) = 38.51, \ p < .0001 \]. Post-hoc analyses indicated that the
parietal site (11.57 uV) generated significantly more positive mean amplitudes than the
frontal (4.89 uV), central (8.57 uV), and occipital (7.80 uV) sites. Furthermore, central
and occipital sites did not significantly differ but their respective mean amplitudes were
significantly greater than the mean amplitude at the frontal site. There was also a
significant 2-way interaction between Sex and Vertex site \[ F(3,54) = 7.88, \ p = .0002 \],
which is presented in Figure 3.49. Post-hoc analyses indicated that at the occipital sites
males generated smaller amplitudes than females.

Additional analyses for unilateral trials showed a significant main effect for
Vertex site \[ F(3,54) = 37.06, \ p < .0001 \], a significant 2-way interaction between Sex and
Vertex site \[ F(3,54) = 7.23, \ p = .003 \], and a significant 4-way interaction between Sex,
Condition, Visual field, and Vertex site \[ F(3,54) = 7.23, \ p = .002 \]. For bilateral trials
there was also a significant main effect for Vertex site \[ F(3,54) = 38.15, \ p < .0001 \] and a
significant 2-way interaction between Sex and Vertex site \[ F(3,54) = 8.24, \ p = .003 \]. The
above effects parallel those for the all trails analysis and will not be further analyzed.

**Lateral sites.** For lateral sites the ANOVA showed a statistically significant main
effect of Condition \[ F(1,18) = 7.07, \ p = .008 \], with greater amplitudes for congruent trails
(7.62 uV) than for incongruent trails (7.04 uV). There was also a significant main effect
Interaction between Sex and Hemisphere for P3 mean amplitudes at lateral sites in a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p-values for pairwise comparisons of means).

Results also indicated a significant main effect for Hemisphere \[ F(1,18) = 11.78, p = .003 \], with the RH generating greater amplitudes (7.79 uV) than the LH (6.88 uV). There were several statistically significant interactions: Sex and Lateral site \[ F(4,72) = 8.41, p = .001 \], Visual field of the word and Hemisphere \[ F(1,18) = 22.00, p = .0002 \], Presentation, Visual field of the word, and Hemisphere \[ F(1,18) = 42.99, p < .0001 \], Visual field of the word, Lateral sites, and Hemisphere \[ F(4,72) = 9.87, p < .0001 \], Presentation, Visual field of the word, Lateral
sites, and Hemisphere \([F(4,72) = 51.39, p < .0001]\), and Sex, Condition, Presentation, Lateral sites, and Hemisphere \([F(4,72) = 3.78, p = .01]\). Only the 4-way interaction will be discussed since the lower order interactions can be explained by the effects in the higher order interactions.

The interaction between Presentation, Visual field of the word, Lateral sites, and Hemisphere is presented in Figure 3.50 for unilateral and bilateral presentations, respectively. For unilateral trials, post-hoc analyses indicated that over the RH, amplitudes were larger for ipsilateral (RVF) than for contralateral (LVF) presentations for all three posterior sites. A similar pattern was found over the LH, but only for temporal sites (see Figure 3.50 A). Thus, at the temporal sites, P3 amplitudes were larger for ipsilateral VF-hemisphere combinations than for contralateral combinations. For bilateral presentations, post-hoc analyses showed that LVF-face/RVF-word presentations evoked greater amplitudes at the temporal site over the LH than LVF-word/RVF-face the presentations. However, over the RH, the LVF-word/RVF-face trials generated greater amplitudes than the LVF-face/RVF-word trials at the temporal and occipital sites (see Figure 3.50 B). Thus for bilateral presentations, P3 amplitudes at temporal sites were larger for ipsilateral VF-face and hemisphere combinations than for contralateral combinations. Taken together, for both unilateral and bilateral presentations, temporal P3 amplitudes appear to be dependent on the VF of the face in a paradoxical fashion (i.e., larger amplitudes for indirect projections).
Figure 3.50

Interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere for mean amplitudes of P3 component at lateral sites in a lateralized Face/Word Stroop analog - face target task (numbers in figure represent p-values for pairwise comparisons of means)

A) unilateral presentations

B) bilateral presentations
The ANOVA for unilateral presentations revealed a significant main effect for Lateral site \(F(4,72) = 23.49, p < .0001\), a main effect for Hemisphere \(F(1,18) = 10.80, p = .004\), a significant 2-way interaction between Sex and Hemisphere \(F(1,18) = 7.46, p = .002\), a 2-way interaction between Visual field and Hemisphere \(F(1,21) = 55.74, p < .0001\), a 3-way interaction between Visual field, Lateral site, and Hemisphere \(F(4,72) = 48.95, p < .0001\), and a 4-way interaction between Sex, Condition, Visual field, and Lateral site \(F(4,72) = 5.09, p = .01\). For bilateral presentations there was a statistically significant main effect for Lateral site \(F(4,72) = 23.27, p < .0001\), a main effect for Hemisphere \(F(1,18) = 11.83, p = .003\), a significant 2-way interaction between Sex and Hemisphere \(F(1,18) = 8.98, p = .001\), a 2-way interaction between Visual field of the word and Hemisphere \(F(1,21) = 20.25, p = .0003\), and a 4-way interaction between Sex, Condition, Lateral site, and Hemisphere \(F(4,72) = 4.27, p = .01\). All of these effects have been addressed in the analysis for all trials (see Figure 3.20).

**P3 Component - Peak Amplitudes and Latencies**

Additional ANOVAs were performed for the P3 component using peak amplitudes and peak latencies as dependent measures. Peak amplitudes yielded the same findings as the analyses with mean amplitudes. The ANOVAs with peak latencies as a dependent measure did not provide any evidence that support the view that P3 latencies are affected by the SE.

**Summary**

The newly developed face/word Stroop analog task with face targets provided several unexpected results across all ERP complexes and components. The Sex factor
interacted with other experimental variables, however, because of the small sample size of males and females the findings involving sex will not be discussed except for replications with other experiments.

**N1/P1 anterior complex.** Surprisingly, results for the exogenous anterior N1/P1 complex showed a SE such that incongruent trials evoked more negative mean amplitudes than congruent trials. Greater negativity for the incongruent than the congruent condition was found for unilateral presentations over the central and frontal sites and for bilateral presentations only over the frontal sites (see Figure 3.40). For the anterior N1/P1 complex a greater negativity was found for LVF than for RVF presentations. Unilateral LVF trials evoked more negative amplitudes than RVF trials over both hemispheres (see Figure 3.40). In addition, unilateral RVF trials showed more negative mean amplitudes over the frontal than over the central sites (see Figure 3.38). For bilateral presentations, however, the LVF-word/RVF-face trials evoked more negative amplitudes than LVF-face/RVF-word trials only over the LH (see Figure 3.41).

**P1/N1 posterior complex.** Posterior P1/N1 complex mean amplitudes were more negative over the LH than over the RH and more so over the temporal sites than parietal and occipital sites. In addition, unilateral LVF presentations generated more negative amplitudes than RVF presentations (see Figure 3.42), at least for parietal sites (see Figure 3.44). Unexpectedly, for the posterior P1/N1 complex there was also a SE as evidenced by greater negativity for incongruent than for congruent trials (see Figure 3.43). As in previous experiments, the posterior P1/N1 complex indicated early laterality effects. Unilateral LVF presentations evoked greater negativity than RVF presentations over
parietal and occipital lateral sites over both hemispheres, but only at the temporal site of
the RH (i.e., direct projections) (see Figure 3.45 A). For bilateral presentations, however,
the LVF-face/RVF-word trials generated more negative amplitudes than the LVF-
word/RVF-face trials at the occipital sites over both hemispheres and at the temporal site
over the RH (i.e., direct projection of the face) (see Figure 3.45 B). In addition, unilateral
presentations showed marked latency shifts between ipsilateral and contralateral
projections such that there was on average an IHTT of approximately 26 msec for the P1
peak and 20 msec for the N1 peak (see Tables 3.5 and 3.6).

**N2 component.** N2 mean amplitudes were significantly larger for left than for right
temporal recordings (see Figure 3.47). Unilateral RVF presentations generated larger N2
amplitudes over the LH (i.e., direct projections) than over the RH (i.e., indirect
projections), whereas there was no laterality effect for LVF presentations. In addition, for
bilateral presentations, LVF-word/RVF-face trials generated larger N2 amplitudes over
the LH than over the RH (see Figure 3.48). It appears that for the N2 component,
presentations of the face in the RVF, either with a word in the same or opposite VF,
generated more negative amplitudes over the LH than over the RH.

**P3 component.** As expected, there was a SE for P3 amplitudes, whereby the P3
was larger for congruent than for incongruent presentations, as was also found with the
two previous experiments. The greatest P3 mean amplitudes were found over the parietal
sites, and the RH generated greater amplitudes than the LH. Consistent with Experiment
1, laterality effects were present. Unilateral RVF presentations generated greater P3
amplitudes than LVF over the central, temporal, parietal, and occipital sites over the RH
(i.e., indirect projections), while the LVF presentations generated greater P3 amplitudes only at the temporal site over the LH (i.e., indirect projections) (see Figure 3.50 A). For bilateral presentations, LVF-word/RVF-face trials generated greater amplitudes than LVF-face/RVF-word at the temporal and occipital sites over the RH (i.e., indirect face projections), while LVF-face/RVF-word trials generated greater P3 amplitudes than LVF-word/RVF-face at the temporal site over the LH (i.e., indirect face projections) (see Figure 3.50 B). In other words, when one focuses on the VF of the face (i.e., target stimulus) the temporal sites reveal reliable, but paradoxical, laterality effects for both unilateral and bilateral presentations. For a given hemisphere, ipsilateral face presentations result in larger P3 amplitudes than contralateral presentations.

Discussion

To my knowledge there has been no published research with a lateralized face/word Stroop analog task. Therefore, direct comparisons with prior research is not possible. However, comparisons of an indirect nature will be made with word-picture Stroop analogs as well as with the lateralized face tasks. In addition, findings from Experiment 1 and 2 will also serve for comparisons.

Behavioral Data

As expected, the face/word Stroop analog task in which the participants identified the faces as man’s, woman’s, or baby’s while ignoring the face related words indicated a SE of approximately 30 msec. This finding is consistent with results from other picture-word Stroop analogs, most of which showed that the word interfered with the picture naming (for review see MacLeod, 1991). This finding is supportive of the relative speed
of processing model, assuming that word reading is faster than face naming. In addition, the SE for the face/word Stroop analog task is also consistent with the automaticity model, provided that word reading is more automatic than face naming. Lateralized presentation of the face/word Stroop analog was primarily employed in order to investigate hemispheric asymmetries. It was assumed that the two components of the face/word Stroop analog task would relate to LH superiority for words and RH superiority for faces, respectively. It was further assumed that there would be a greater SE when the word, either together with face in the same VF (i.e., unilateral presentation) or in the opposite VF (i.e., bilateral presentation), was presented in the RVF. This assumption parallels that of lateralized presentations of the classical Stroop stimuli where a greater SE is expected when the word is presented to the language dominating LH.

Experiment 3 did not show hemispheric asymmetries with respect to the SE for unilateral presentations, however, for bilateral presentations there was a greater SE for LVF-face/RVF-word presentations than for LVF-word/RVF-face presentations. In other words, when the word was initially presented to the language specialized LH, it interfered more with face identification than when the word was presented to the language inferior RH. Consistent with Experiment 1, there were practice effects for Experiment 3 (see Figure 3.37). With practice, females, but not males, showed improvement in performance of the lateralized face/word Stroop analog task. This finding might be explained in terms of the differences in motivation or strategy between males and females.
ERP Data

Laterality effects - direct versus indirect anatomical pathways. Consistent with the previous two experiments, the lateralized face/word Stroop analog task - face target showed early laterality effects for the posterior P1/N1 complexes due to the VF-hemisphere manipulations for unilateral presentations. Larger amplitudes and earlier peak latencies were found for direct LVF-RH combinations than for indirect RVF-RH combinations (see Figure 3.45 A and Figure 3.46). Surprisingly, equivalent laterality effects for P1/N1 amplitudes were absent over the LH, although the predicted latency effects were found. Consistent with Experiments 1 and 2, direct projections showed earlier peak latencies than indirect projections for the P1 component (i.e., 13 to 37 msec) and for the subsequent N1 component (i.e., 6 to 33 msec). Unexpectedly, but consistent with Experiments 1 and 2, paradoxical laterality effects were observed for the P3 amplitudes at the LH temporal site and at the central, temporal, parietal and occipital sites over the RH (see Figure 3.50 A). Thus, these paradoxical laterality effects for P3 amplitudes were most consistent for the temporal sites. For unilateral presentations at the previously mentioned sites, there were greater P3 amplitudes for ipsilateral than for contralateral projections. Greater P3 amplitudes over the RH might be explained by a carry-over effect from the preceding N1 component (see Figure 3.46). However, the same interpretation cannot explain the LH temporal site finding, since the preceding N1 amplitudes for ipsilateral and contralateral presentations are equivalent (see Figure 3.46). Consistent laterality effects, only for temporal sites, were also present for bilateral presentations. For a given hemisphere, P3 amplitudes were larger when the face stimulus
was presented in the ipsilateral (indirect), rather than contralateral (direct), VF condition (see Figure 3.50 B). Apparently, the paradoxical P3 effect for the temporal sites is driven by the VF of the face stimulus, irrespective of the VF of the word. An additional observation regarding paradoxical laterality effects for P3 amplitudes is the comparison of P3 amplitudes at the parietal sites. In ERP research, the P3 amplitudes from parietal sites are usually reported, since the P3 amplitudes are typically the greatest at parietal sites. Sometimes it is assumed that the P3 is generated within the parietal region and that recordings from neighboring sites, such as temporal sites, merely reflect volume conduction from parietal generators. However, a comparison of P3 amplitudes from parietal and temporal sites in Experiment 3 indicates that even though the temporal P3 amplitudes are much smaller than parietal P3 amplitudes, the pattern of P3 amplitudes with respect to the VF-hemisphere manipulations at temporal sites are different from that of parietal sites. The parietal P3 amplitudes showed paradoxical laterality effects only over the RH parietal site for the unilateral RVF projections (see Figure 3.50 A), while temporal P3 amplitudes indicated paradoxical laterality effects over both hemispheres. Thus, there is a clear dissociation between temporal and parietal P3 amplitudes, contradicting the volume conduction interpretation, and instead indicating separate generators for temporal and parietal P3 components.

Laterality effects - hemispheric specialization. As already mentioned, the face/word Stroop analog task was based on the assumptions of LH superiority for word processing and a RH superiority for a face processing. The first evidence for hemispheric specialization was for the early anterior N1/P1 complex, where amplitudes over the LH
were more positive for RVF than for LVF words, irrespective of the VF of the face presentations (i.e., unilateral or bilateral presentations). On the other hand, over the RH there were more positive amplitudes for RVF than for LVF presentations, but only for unilateral presentations (see Figure 3.41). Together, these findings may reflect LH superiority for words, as reflected by VF of input, but not by hemisphere of recording site.

For the posterior P1/N1 component, at occipital sites there were more negative amplitudes over both hemispheres for LVF faces than for RVF faces, for unilateral as well as for bilateral presentations (see Figure 3.45). This LVF effect for faces is consistent with RH specialization for faces. It is interesting that the ERP laterality effects appear to depend more on VF of input than hemisphere of recording site. It may be that the specialized hemisphere activates both hemispheres. Alternatively, regionally lateralized effects may be difficult to discern given the limited spatial resolution of EEG. At the parietal sites, for the posterior P1/N1 component, there were more negative amplitudes over both hemispheres for unilateral LVF presentations, while for bilateral presentations, parietal P1/N1 amplitudes were unaffected by VF of the word or face. This finding indicates a dissociation of occipital and parietal P1/N1 effects, perhaps reflecting different stage of face processing. The findings for the P1/N1 temporal sites were already mentioned with respect to direct versus indirect pathway effects. However, the finding that over the RH, but not LH, there were more negative amplitudes for LVF faces than for RVF faces, irrespective of the VF of the word, is consistent with RH superiority for faces (see Figure 3.45).
Hemispheric specialization was also indicated by findings from the N2 component, where more negative amplitudes were found over LH than over RH temporal sites (see Figure 3.47). In addition, there were more negative amplitudes over the LH than over the RH for RVF face presentations for both unilateral and bilateral presentations, irrespective of the VF of the word (see Figure 3.48). No such hemispheric asymmetries in N2 amplitudes were found for LVF (RH) face presentations. This suggests that RH face projections produce hemispheric N2 responses (i.e., N2 of equal amplitudes over both hemispheres), whereas LH face projections result in an N2 response that remains mainly within LH (larger N2 over LH than over RH).

SE. As in Experiment 1, an ERP SE was first observed for the early exogenous anterior N1/P1 and posterior P1/N1 complexes, interacting in a complex fashion with other variables that usually included sex. Unlike Experiment 1, there was also a main effect of condition whereby the incongruent condition generated more negative N1/P1 and P1/N1 amplitudes than the congruent condition over anterior as well as posterior sites. Greater negativity for the incongruent than the congruent condition may indicate greater need for attentional resources for the incongruent presentations. As in Experiment 1, the congruent condition generated greater P3 amplitudes than the incongruent condition. This suggests that the P3 reflects the ease of processing the Stroop stimuli. Unlike Experiment 1, the SE in Experiment 3 was essentially invariable to laterality factors. The one exception was a 5-way interaction in which SE was present in a relatively complex interaction that included sex. Thus, the SE may differ between males and females, but due to the small sample sizes of males and females and to the
complexity of the interaction, these findings may represent spurious effects. The lack of
electrophysiological hemispheric asymmetries and the presence of the behavioral
hemispheric asymmetries with respect to the SE in Experiment 3 is contrary to the
findings in Experiment 1.

The final experiment was designed to be the compliment of Experiment 3. For
Experiment 4, the same stimulus set as in Experiment 3 was used, the only difference was
that the participants were to respond to the words and ignore the faces. Since faces serve
as the interfering stimuli, greater interference effects are expected when the face is
projected to the LVF, due to RH superiority for face processing.
EXPERIMENT 4: LATERALIZED FACE/WORD STROOP ANALOG - WORD

TARGET TASK

Behavioral Data

Reaction times were entered into a 2x2x2x2x2 mixed factorial ANOVA, with Sex (male, female) as a between-subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the Word (left visual field - LVF, right visual field - RVF), and Block (block 1, block 2) as within subjects factors. All post-hoc analyses were carried out using the Tukey honestly significant difference (HSD) test.

The analysis of latencies revealed a significant main effect of Condition \( F(1,22) = 95.83, p < .0001 \), with faster RTs for congruent (\( M = 707 \) msec) than for incongruent trials (\( M = 764 \) msec). There was also a statistically significant main effect of Block \( F(1,22) = 5.18, p = .03 \), indicating that with practice overall RTs decreased from the first block of trials (\( M = 746 \) msec) to the second block (\( M = 725 \) msec).

The ANOVA also revealed statistically significant 2-way interactions between Sex and Block \( F(1,22) = 5.27, p = .03 \), and between Presentation and Visual field of the word \( F(1,22) = 5.42, p = .03 \). The interaction between Sex and Block is presented in Figure 3.51. Post-hoc analyses showed that only females improved with practice.

The interaction between Visual field of the word and Presentation is presented in Figure 3.52. Post-hoc analyses revealed no VF differences for unilateral presentations, whereas for bilateral presentations there was a tendency that LVF-face/RVF-word presentations were faster than the LVF-word/RVF-face presentations.
Additional ANOVAs (4-way) were performed separately for unilateral and bilateral trials to further tease apart Visual field effects. For unilateral trials, the levels of the Visual field factor are LVF and RVF, while for bilateral trials the levels are LVF-word/RVF-face and RVF-word/LVF-face. Since several of the significant effects parallel those of the 5-way analysis, only novel findings involving the Visual field factor will be presented.

The ANOVA for unilateral trials revealed a significant 4-way interaction between Sex, Condition, Visual field, and Block $[F(1,22) = 5.79, p = .02]$. In order to disentangle this complex interaction, difference scores were used. However, post-hoc analyses indicated that for all pairwise comparisons $p > .20$. 
Interaction between Presentation and Visual field of the word for a lateralized Face/Word Stroop analog - word target task (number in the figure represent p-values for pairwise comparison of means)

The ANOVA for bilateral trials revealed a significant main effect of Visual field [$F(1,22) = 10.04, p = .004$] with faster RTs for LVF-face/RVF-word ($M = 723$ msec) than for LVF-word/RVF-face ($M = 739$ msec) trials, as seen in Figure 3.52. With respect to the objectives of the present research, it is necessary to mention the interaction between Condition and Visual field [$F(1,22) = 3.95, p = .06$] which approached statistical significance, and is shown in Figure 3.53 A. Post-hoc analyses indicated that for congruent presentations there were no significant differences between LVF-word/RVF-face and LVF-face/RVF-word trials. However, there were longer RTs for the LVF-word/RVF-face presentations than for LVF-face/RVF-word presentations, indicating a
greater interference effect (i.e., the difference between incongruent and congruent trials) for the LVF-word/RVF-face than for the LVF-face/RVF-word presentations.

In summary, the results indicate that there was a considerable interference effect for the Face/Word Stroop analog task with word targets in the order of 57 msec (greater than 30 msec interference from the Face/Word Stroop analog task with face targets). This SE was the greatest of all four tasks. Consistent with previous experiments, this task also showed a practice effect for females but not males. With respect to hemispheric asymmetries, unilateral presentations did not show laterality effects, while for bilateral presentations, the trials with word projections to the language dominant LH and face projections to the RH (i.e., RVF-word/LVF-face trials) were faster than the reverse (see Figure 3.52). This suggests that when both hemispheres receive stimulus information, word target identification is optimal when the word target is lateralized to the language specialized LH. Regarding SEs in Experiment 4, we did not find any laterality effects for unilateral presentations as was the case with face targets (Experiment 3). However, for bilateral incongruent presentations, RTs were faster when the word was projected to the language specialized LH and the face to the face specialized RH than for the reverse condition, as shown in Figure 3.53 A. No laterality effects were present for the congruent condition. Thus, the results are contrary to the prediction that there would be greater SE for the LVF face presentations. In fact, for bilateral presentations, the SE was smaller when the faces were presented in the LVF indicating that the RH dominance for face processing does not play a critical role in generating SE for this task. This finding is just opposite from that of Experiment 3, in which participants responded to the same set of
stimuli but identified the face and ignored the word. That is, for incongruent bilateral presentations, RTs were faster when the words and the faces were initially projected to the non-dominant hemispheres (i.e., word to the RH and face to the LH) than when they were projected to the dominant hemispheres (see Figure 3.53 B). If one considers the VF/Hemisphere combination of the target for bilateral presentations, a consistent pattern emerges from both experiments using face/word Stroop analog task. SEs are larger for RH, than for LH, target presentations. Rather than finding opposite laterality effects for face and word target task, a single overall effect is present. It appears that both hemispheres can do both tasks, and that the LH is better shielded from interfering RH influences, than the reverse.
Figure 3.53

Interaction between Condition and Visual Field of the word for bilateral trial in a
lateralized Face/Word Stroop analog task (numbers in the figure represent p-values for
pairwise comparisons of means)

A) Word target (Experiment 4)

B) Face target (Experiment 3)
ERP Data

Typical ERPs waveforms for the lateralized Face/Word Stroop analog task with word target are presented in Figure 3.54. Several components were identified for Experiment 4: anterior N1/P1 complex, posterior P1/N1 complex, N2, and P3 components.

For each complex and component two principal analyses were performed, one for vertex sites and one for lateral sites. For vertex sites, mean amplitudes were entered into a 2x2x2x2x4 mixed factorial ANOVA with Sex (males, females) as a between subjects factor and Condition (congruent, incongruent), Presentation (unilateral, bilateral), Visual field of the word (LVF, RVF), and Vertex site (Fz, Cz, Pz, and Oz) as within subject factors. Lateral sites had a similar design except that the vertex site variable was replaced by two other variables: Lateral site [frontal (F3/F4), central (C3/C4), temporal (T5/T6), parietal (P3/P4), and occipital (O1/O2)], and Hemisphere [left hemisphere (LH), right hemisphere (RH)].

Anterior N1/P1 Complex - Mean Amplitude Between 100 and 220 msec

Vertex sites. There were no significant findings at the vertex sites for the anterior N1/P1 complex.

Lateral sites. For lateral sites (i.e., F3, F4, C3, and C4) an ANOVA revealed a significant main effect of Lateral site \([F(1,22) = 26.93, p < .0001]\) with the central sites generating more negative amplitudes (.33 uV) than the frontal sites (1.01 uV). A significant main effect for Lateral site was also found in separate analyses for unilateral presentations \([F(1,22) = 27.69, p < .0001]\) and for bilateral presentations \([E(1,22) = 27.69, p < .0001]\).
ERP waveforms for congruent and incongruent presentations in a lateralized Face/Word Stroop analog - word target task.
20.84, \( p = .0001 \), respectively. For unilateral trials there was also a significant interaction between Condition, Visual field, and Lateral site \([F(1,22) = 7.84, p = .01]\), as shown in Figure 3.55. Post-hoc analyses revealed that the incongruent condition generated more negative amplitudes than congruent condition over the frontal sites irrespective of VF in which the stimuli were presented. The same pattern was found over the central site but only for the LVF presentations.

Figure 3.55

Interaction between Condition, Visual field, and Lateral site for mean amplitudes of the anterior N1/P1 complex at lateral sites for unilateral presentations in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means)
Posterior P1/N1 Complex - Mean Amplitude Between 80 and 220 msec

**Vertex sites.** For vertex sites (i.e., Pz and Oz) an ANOVA revealed a significant interaction between Sex and Visual field \( [F(1,22) = 7.99, p = .01] \), as shown in Figure 3.56. Post-hoc analyses indicated that females generated more negative amplitudes than males, especially for RVF word presentations. The ANOVA for bilateral presentations revealed a significant interaction between Sex and Visual field of the word \( [F(1,22) = 8.74, p = .01] \) which parallels the all trials analysis and is shown in Figure 3.56.

**Figure 3.56**

Interaction between Sex and Visual field of the word for mean amplitudes of the posterior P1/N1 complex at vertex sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means)
Lateral sites. For lateral sites (i.e., T5, T6, P3, P4, O1, and O2) an ANOVA revealed a significant main effect of Lateral site \([E(2,44) = 7.35, p = .01]\). Post-hoc analyses showed that the mean amplitudes at the temporal sites (-.73 uV) were significantly more negative than at the occipital sites (-.26 uV) and the parietal sites (-.10 uV). There was also a significant 2-way interaction between Sex and Visual field of the word \([E(1,22) = 7.17, p = .01]\), a 2-way interaction between Visual field of the word and Hemisphere \([E(1,22) = 23.18, p = .0001]\), and a 3-way interaction Sex, Visual field of the word, and Hemisphere \([E(1,22) = 7.19, p = .01]\).

The interaction between Sex, Visual field, and Hemisphere is presented in Figure 3.57. Post-hoc analyses indicated that females, but not males, showed sensitivity to the VF factor: over the LH females generated more negative amplitudes for LVF-word/RVF-face presentations (i.e., face directly projected to the LH) than for LVF-face/RVF-word presentations (i.e., word directly projected to the LH).

An ANOVA for posterior P1/N1 mean amplitudes for just unilateral trials revealed a significant main effect for Lateral site \([E(2,44) = 6.31, p = .004]\), equivalent to findings for the all trials analysis. There was also a significant 2-way interaction between Visual field and Hemisphere \([E(1,22) = 8.61, p = .008]\), as shown in Figure 3.58. Post-hoc analyses indicated that LVF presentations generated greater more negative amplitudes than RVF presentations over the RH (i.e., contralateral hemisphere).

For bilateral presentations, the ANOVA showed a statistically significant main effect of Lateral site \([E(2,44) = 7.74, p = .001]\), the same as for all trials. There was also a significant 2-way interaction between Sex and Visual field of the word \([E(2,22) = 9.37, p = .001]\).
Figure 3.57

Interaction between Sex, Visual field, and Hemisphere for mean amplitudes of the posterior P1/N1 complex at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means).

Figure 3.58

Interaction between Visual field and Hemisphere for mean amplitudes of the posterior P1/N1 complex for unilateral trials at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means).
Figure 3.59

Interaction between Visual field of the word and Hemisphere for mean amplitudes of the posterior P1/N1 complex for bilateral trials at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means)

Figure 3.60

Interaction between Visual field of the word and Lateral site for mean amplitudes of the posterior P1/N1 complex for bilateral trials at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means)
There was also a significant 2-way interaction between Visual field of the word and Hemisphere \([F(1,22) = 24.15, p = .001]\), and a significant 2-way interaction between Visual field of the word and Lateral site \([F(2,44) = 6.47, p = .004]\).

The interaction between Visual field of the word and Hemisphere is presented in Figure 3.59. Post-hoc analyses indicated that over the LH the RVF-word presentations (i.e., direct projections) evoked more negative amplitudes than LVF-word presentations (indirect projections).

The interaction between Visual field of the word and Lateral site is presented in Figure 3.60. Post-hoc analyses indicated that LVF-face/RVF-word presentations evoked more negative amplitudes than LVF-word/RVF-face presentations over the temporal and occipital sites.

Posterior Pl/N1 Complex - Positive Peak Amplitudes

An ANOVA for positive peak amplitudes revealed a significant 2-way interaction between Lateral site and Hemisphere \([F(2,44) = 5.72, p = .009]\) and a 3-way interaction between Presentation, Visual field of the word, and Hemisphere \([F(1,22) = 12.06, p = .002]\). The interaction between Lateral site and Hemisphere is shown in Figure 3.61. Post-hoc analyses indicated that were more positive amplitudes at the temporal site over the RH than over the LH.

The interaction between Presentation, Visual field of the word, and Hemisphere is presented in Figure 3.62. Post-hoc analyses showed that for bilateral presentations LVF-
face/RVF-word trials evoked more positive amplitudes over the RH (i.e., face directly projected to the RH) than over the LH (i.e., word directly projected to the LH).

An ANOVA for posterior P1/N1 positive peak amplitudes for unilateral trials revealed a significant 2-way interaction between Lateral site and Hemisphere \([F(2,44) = 5.94, p = .009]\), which parallels that shown in Figure 3.61. Additional analyses for bilateral presentations revealed a significant 2-way interaction between Visual field of the word and Hemisphere \([F(1,22) = 32.18, p < .0001]\), which is similar to that shown in Figure 3.62.

Figure 3.61

Interaction between Lateral site and Hemisphere for peak positive amplitudes of the posterior P1/N1 complex at vertex sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means)
Interaction between Presentation, Visual field of the word, and Hemisphere for positive peak amplitudes of the posterior P1/N1 complex at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means)

Posterior P1/N1 Complex - Negative Peak Amplitudes

An ANOVA for negative peak amplitudes revealed a significant main effect of Lateral site \[F(2,44) = 14.32, \ p < .0001\], a 2-way interaction between Sex and Visual field of the word \[F(1,22) = 13.79, \ p = .001\], and a 2-way interaction between Visual field of the word and Hemisphere \[F(1,22) = 17.98, \ p = .0003\], which are equivalent to those found with mean amplitudes. There was also significant 4-way interaction between Sex, Presentation, Lateral site and Hemisphere \[F(2,44) = 5.95, \ p = .006\], as shown in Figure 3.63. Post-hoc analyses indicated that for unilateral and bilateral presentations females generated more negative amplitudes at the temporal and parietal sites over the RH than over the LH.
Additional analyses for unilateral presentation revealed a statistically significant main effect for Lateral site \( [F(2,44) = 14.67, p < .0001] \), and a significant 2-way interaction between Visual field and Hemisphere \( [F(1,22) = 10.94, p = .003] \). These effects are equivalent to those found with all trials. An ANOVA for bilateral presentations showed only a statistically significant main effect for Lateral site \( [F(2,44) = 12.67, p < .0001] \), and a 2-way interaction between Sex and Visual field of the word \( [F(1,22) = 12.34, p = .002] \) (see Figure 3.57). These effects were also equivalent to that found in analyses with mean amplitudes for all trials.

**Posterior P1/N1 Complex - Peak Latencies**

Peak latencies measurement of the P1 and N1 components at the temporal, parietal and occipital sites over both hemispheres for LVF and RVF unilateral presentations as well as the difference between ipsilateral and contralateral peak latencies [also referred to as Interhemispheric Transfer Time (IHTT)] are presented in Tables 3.7 and 3.8. Latency shifts for the P1 are between 27 and 37 msec, while latency shifts for the subsequent N1 component are between 15 and 21 msec. Thus, latency shifts of the P1 and N1 components due to direct or indirect projection of the face/word Stroop analog stimuli indicated that the IHTTs were shorter for the N1 component than for the P1 component. Contralateral VF-hemisphere projections to the temporal sites over both hemispheres generated earlier peak amplitudes for P1 and N1 components than ipsilateral projections, as shown in Figure 3.64.
Figure 3.63

Interaction between Sex, Presentation, Lateral site, and Hemisphere for negative peak amplitudes of the posterior P1/N1 complex at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p values for pairwise comparisons of means)

A) Unilateral presentations

B) Bilateral presentations
Table 3.7

Peak latencies (msec) of the posterior P1 component for temporal, parietal and occipital sites over both hemispheres in a lateralized Face/Word Stroop analog - word target task (IHTT signifies Inter-Hemispheric Transfer Time).

| Site      | LH | | | RH | | | |
|----------|---|---|---|---|---|---|
|          | Ipsilateral | Contralateral | IHTT | Ipsilateral | Contralateral | IHTT |
| Temporal | 131 | 99 | 32 | 129 | 101 | 28 |
| Parietal | 126 | 99 | 27 | 126 | 95  | 31 |
| Occipital | 131 | 96 | 35 | 132 | 95  | 37 |

Table 3.8

Peak latencies (msec) of the posterior N1 component for temporal, parietal and occipital sites over both hemispheres in a lateralized Face/Word Stroop analog - word target task (IHTT signifies Inter-Hemispheric Transfer Time).

| Site      | LH | | | RH | | | |
|----------|---|---|---|---|---|---|
|          | Ipsilateral | Contralateral | IHTT | Ipsilateral | Contralateral | IHTT |
| Temporal | 189 | 171 | 18 | 189 | 171 | 18 |
| Parietal | 183 | 168 | 15 | 183 | 162 | 21 |
| Occipital | 186 | 171 | 15 | 195 | 174 | 21 |
ERP waveforms for left (T6) and right (T5) temporal sites during unilateral LVF and RVF presentations of Face/Word Stroop analog - word target stimuli. Note the latency and amplitude differences between contralateral and ipsilateral VF-hemisphere conditions.

**N2 Component - Mean Amplitude Between 220 and 300 msec**

**Vertex sites.** There were no significant findings at vertex sites for the N2 component.

**Lateral sites.** An ANOVA showed a statistically significant main effect of Hemisphere [$\text{F}(1,22) = 11.40, p = .003$], with the LH generating more negative mean amplitudes (1.01 uV) than the RH (1.70 uV). There was also a significant 2-way interaction between Condition and Lateral site [$\text{F}(4,88) = 5.40, p = .01$], and a significant 2-way interaction between Lateral site and Hemisphere [$\text{F}(4,88) = 11.67, p < .0001$].
The interaction between Condition and Lateral site is presented in Figure 3.65. Post-hoc analyses indicated that over the frontal sites the incongruent trials generated larger N2 amplitudes than the congruent trials.

The interaction between Lateral site and Hemisphere is presented in Figure 3.66. Post-hoc analyses indicated that N2 mean amplitudes at the temporal and parietal sites were larger over the LH than over the RH.

Figure 3.65

Interaction between Condition and Lateral site for mean amplitudes of the N2 component at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p-values for pairwise comparisons of means)

An additional ANOVA for unilateral trials revealed only a significant main effect for Hemisphere \[F(1,22) = 15.43, p = .0007\], and a 2-way interaction between Lateral site and Hemisphere \[F(4,88) = 11.60, p < .0001\] that parallels that of Figure 3.66. An
ANOVA for bilateral trials also revealed a significant 2-way interaction between Lateral site and Hemisphere \[F(4,88) = 11.12, p < .0001\], that is equivalent to that found with all trials as shown in Figure 3.66.

Figure 3.66

Interaction between Lateral site and Hemisphere for mean amplitudes of the N2 component at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p-values for pairwise comparisons of means)

P3 Component - Mean Amplitudes Between 300 and 500 msec

Vertex sites. An ANOVA for vertex sites showed a statistically significant main effect for Condition \[F(1,22) = 22.22, p = .0001\], with the congruent condition generating larger P3 amplitudes (7.45 uV) than the incongruent condition (6.43 uV). There was also a statistically significant main effect for Presentation \[F(1,22) = 10.07, p = .004\], with
bilateral presentations evoking greater P3 amplitudes (7.19 uV) than unilateral presentations (6.68 uV). In addition, there was also a statistically significant main effect for Vertex site [$F(3,66) = 29.69, p < .0001$]. Post-hoc analyses indicated that the parietal site (9.91 uV) generated significantly larger mean P3 amplitudes than the frontal (4.58 uV), central (7.11 uV), and occipital (6.14 uV) sites. Furthermore, central and occipital sites did not significantly differ in mean amplitudes but they generated significantly greater mean amplitudes than the frontal site.

Additional analyses for unilateral trials showed significant main effects for Condition [$F(1,22) = 15.53, p = .0007$] and Vertex site [$F(3,66) = 28.51, p < .0001$]. For bilateral trials there were also significant main effects for Condition [$F(1,22) = 12.21, p = .002$] and Vertex site [$F(3,66) = 28.75, p < .0001$]. The above effects parallel those for the all trials analyses and will not be further analyzed.

Lateral sites. For lateral sites, an ANOVA showed a statistically significant main effect of Condition [$F(1,22) = 21.90, p = .008$], and a significant main effect of Presentation [$F(1,22) = 7.05, p = .01$], which were equivalent to those found at the vertex sites. There was also a significant main effect of Lateral site [$F(4,88) = 13.23, p < .0001$], which was similar to that found at the vertex site. In addition, for Lateral site factor, P3 mean amplitudes for temporal sites were equivalent to those from the central and occipital sites. There were several statistically significant interactions: Visual field of the word and Hemisphere [$F(1,22) = 9.89, p = .005$], Presentation, Visual field of the word, and Hemisphere [$F(1,18) = 33.99, p < .0001$], Sex, Presentation, Visual field of the word, and Hemisphere [$F(1,22) = 8.63, p = .008$], and Presentation, Visual field of the
word, Lateral sites, and Hemisphere \([E(4,88) = 12.13, p < .0001]\). Only the four-way interaction will be discussed since the lower order interactions can be explained by the effects in the higher order interactions.

The interaction between Presentation, Visual field of the word, Lateral sites, and Hemisphere is presented in Figure 3.67. For unilateral trials, post-hoc analyses indicate, that over the RH amplitudes were surprisingly larger for ipsilateral (RVF) than for contralateral (LVF) presentations over all sites. No unilateral VF effects were present over the LH. However, for bilateral presentations the only difference was found at temporal sites over the LH where the LVF-face/RVF-word trials generated larger P3 amplitudes than LVF-word/RVF-face trials.

Additional analyses for unilateral presentations showed significant main effect of Condition \([E(1,22) = 16.12, p < .0001]\), a significant 2-way interaction between Visual field and Hemisphere \([E(1,22) = 27.23, p < .0001]\), and a significant 3-way interaction between Visual field, Lateral site, and Hemisphere \([E(4,88) = 12.11, p < .0001]\). For bilateral presentations there was also significant main effect for Condition \([E(1,22) = 12.69, p < .0001]\) and a significant 3-way interaction between Visual field of the word, Lateral site, and Hemisphere \([E(4,88) = 5.43, p = .005]\). The above effects parallel those for the all trial analyses and will not be further analyzed.

**P3 Component - Peak Amplitudes**

Additional ANOVAs were performed for the P3 component, using peak amplitudes and peak latencies as dependent measures. In addition to findings that were similar to that seen for mean amplitudes, analyses yielded a significant 4-way interaction
Figure 3.67

Interaction between Presentation, Visual field of the word, Lateral site, and Hemisphere for P3 mean amplitudes at lateral sites in a lateralized Face/Word Stroop analog - word target task (numbers in figure represent p-values for pairwise comparisons of means)

A) Unilateral presentations

B) Bilateral presentations
between Sex, Visual field of the word, Lateral site, and Hemisphere \( F(4,88) = 5.82, p = .001 \) and a 5-way interaction between Sex, Presentation, Visual field of the word, Lateral site, and Hemisphere \( F(4,88) = 5.08, p = .006 \). Since these highly complex interactions do not include the Condition factor, they will not be further analyzed.

**P3 Component - Peak Latencies**

The analyses with peak latencies as a dependent measure did not provide any significant findings that support the view that the P3 component can be affected by the Stroop task manipulation (i.e., congruent vs. incongruent condition).

**Summary**

For the exogenous posterior P1/N1 complex, several multiway interactions were found involving sex and other experimental factors. Given that these are presumably exogenous components that are known to be driven by perceptual rather than cognitive factors, these effects were surprising and will not be further discussed at this time.

**N1/P1 anterior complex.** Rather surprisingly, the exogenous anterior N1/P1 complex showed a SE for unilateral presentations, whereby the incongruent condition generated more negative amplitudes than the congruent condition over the frontal sites regardless of the VF of the stimuli presentation (see Figure 3.55), and over the central sites only for LVF presentations.

**P1/N1 posterior complex.** Overall, the major findings for the exogenous posterior P1/N1 complex were due to the VF-hemisphere effects. For unilateral presentations, RH, but not LH, recordings exhibit the expected larger (more negative) amplitudes for direct VF than for indirect VF presentations (see Figure 3.58). Interestingly, an opposite pattern
was found for bilateral trials, in which VF effects were only present over the LH (see figure 3.59). Amplitudes were more negative for direct word VF than for indirect word VF presentations. Additionally, bilateral LVF-face/RVF-word presentations generated more negative amplitudes than LVF-word/RVF-face presentations over the temporal and occipital sites, and this may reflect RH specialization for face processing (i.e., LVF face presentations) (see Figure 3.60). Separate analyses for the positive P1 component of the posterior P1/N1 complex showed more positive amplitudes at the temporal sites over the RH than over the LH (see Figure 3.61). In addition, the RH generated more positive amplitudes than the LH for LVF-face/RVF-word presentations (i.e., face presented directly to the RH) (see Figure 3.62). Unilateral presentations showed marked latency shifts between ipsilateral and contralateral projections, resulting in IHTTs of approximately 32 msec and 18 msec for the P1 and N1 peaks, respectively (see Table 3.7 and Table 3.8).

**N2 component.** The SE was also observed for the N2 component as indicated by more negative mean amplitudes for incongruent than congruent trials, but, like for the anterior N1/P1 complex, this effect was only present at the frontal sites (see Figure 3.65). In addition, N2 mean amplitudes were overall larger over the LH than over the RH, at least for the temporal and parietal sites (see Figure 3.66).

**P3 component.** Contrary to our expectations, the only finding related to the SE for the P3 component was a main effect of Condition whereby P3 amplitudes were larger for congruent than for incongruent presentations. P3 amplitudes were largest at parietal sites. In addition, bilateral presentations generated greater P3 amplitudes than unilateral
presentations. For unilateral presentations, P3 amplitudes were greater over the RH for ipsilateral (i.e., indirect) than for contralateral (i.e, direct) stimulus projections (see Figure 3.67 A). However, for bilateral presentations, the only significant finding was observed over the LH temporal site where there were greater P3 amplitudes for LVF-face/RVF-word projections (indirect face projections) than for LVF-word/RVF-face projections (direct face projections).

**Discussion**

As a reminder, the task difference between Experiment 3 and Experiment 4 was only in the target selection; the stimulus set was exactly the same. In Experiment 3 the target was faces, while in Experiment 4 the target was words.

**Behavioral Data**

Rather surprisingly, instructions to identify the word and ignore the face produced a SE, which was the greatest magnitude (approximately 57 msec) of all four experiments. The majority of studies with picture-word Stroop analogs did not find an interference of the picture with word reading. Nevertheless, a few studies using picture-word Stroop analogs (Glaser & Dungelhoff, 1984; Smith & Magee, 1982; Young, Ellis, Flude, McWeeny, & Hay, 1986), in which participants categorized words into respective categories (e.g., categorizing the proper names as politicians or entertainers), reported interference of the picture in the word reading. However, face/word Stroop analog task with word target cannot be considered a categorization task, in that there is only one exemplar for each face category. Regardless of the nature of the face/word Stroop analog task, the finding of a SE with the word-target version is not consistent with either the
relative speed of processing model, or with the automaticity model. A more detailed discussion of this claim will be presented in the general discussion section, along with a comparison of the SEs for Experiments 3 and 4.

With respect to hemispheric asymmetries, it was assumed that the two components of the face/word Stroop analog task would relate to LH superiority for words and RH superiority for faces, respectively. It was further assumed that there would be a greater SE when the to-be-ignored face, either together with word in the same VF (i.e., unilateral presentation) or in the opposite VF (i.e., bilateral presentation), was presented in the LVF (i.e., the face dominant RH). However, Experiment 4 did not show hemispheric asymmetries with respect to the SE for unilateral presentations. On the other hand, for bilateral presentations there was a greater SE for LVF-word/RVF-face presentations than for LVF-face/RVF-word presentations (see Figure 3.53. A). Contrary to our prediction, when the face was initially presented to the face non-specialized LH, it interfered more with word identification than when the face was presented to the face superior RH. Consistent with Experiments 1 and 3, there were also practice effects in Experiment 4 (see Figure 3.51), in which females, but not males, showed improvement in RTs with practice. This might be explained in terms of the differences in motivation or strategy between males and females.

ERP Data

Laterality effects - direct versus indirect anatomical pathways. Consistent with the previous experiments, the lateralized face/word Stroop analog task - word target showed early laterality effects for the posterior P1/N1 complex due to the VF-hemisphere
manipulations for unilateral presentations. Larger (more negative) amplitudes and earlier peak latencies were found for direct LVF-RH combinations than for indirect RVF-RH combinations (see Figure 3.58 and Figure 3.64). Consistent with Experiment 3, laterality effects were found for peak latencies, but not amplitudes, over the LH (see Figure 3.64). Consistent with previous experiments, direct projections showed earlier peak latencies than indirect projections for the earlier P1 component (i.e., 27 to 37 msec) and for the subsequent N1 component (i.e., 15 to 21 msec). Unexpectedly, but consistent with Experiments 1, 2, and 3, paradoxical laterality effects were observed for the P3 component, at least for the RH sites (see Figure 3.67 A). Over the RH there were greater P3 amplitudes for ipsilateral than for contralateral stimulus projections.

Laterality effects - hemispheric specialization. As already mentioned, the face/word Stroop analog task was based on the assumptions of a LH superiority for word processing and a RH superiority for face processing. The first evidence of putative hemispheric specialization effects was found for the early posterior P1/N1 complex. For bilateral trials, amplitudes were more negative for LVF (i.e., RH) than for RVF (i.e., LH) face presentations at occipital and temporal sites (see Figure 3.60). This may reflect RH specialization for face perception for early (occipital) and late (temporal) stages of face processing. When just the P1 component is considered, amplitudes are again larger for RH than for LH temporal sites (see Figure 3.61). A sex difference is apparent when just the N1 component is considered. Amplitudes for the N1 are larger at RH than at LH temporal and parietal sites for females, while no hemispheric difference is found for males (see Figure 3.61). Taken together, these findings are generally consistent with RH
specialization for face perception. Finally, the N2 component was larger over the LH than the RH at temporal sites, as was found in Experiment 3. Apparently, this N2 effect does not depend on the attentional set of the participant (i.e., face vs. word identification), and may reflect a general linguistic component associated with these tasks.

SE. Consistent with Experiments 1 and 3, the SE in Experiment 4 was first observed at the early exogenous anterior N1/P1 complex, albeit expressed in a complex interaction involving Lateral site and VF factors. In Experiment 4, for the early anterior N1/P1 complex, unilateral incongruent conditions generated more negative amplitudes than the congruent conditions over frontal sites irrespective of the VF, while over the central sites the incongruent condition generated more negative amplitudes only for the LVF unilateral presentations (see figure 3.55). Greater negativity for the incongruent than for the congruent condition over frontal sites may indicate a need for greater attentional resources for the incongruent presentations. Over the central sites, the presence of a SE for only unilateral LVF presentations indicates greater susceptibility for the SE when the face/word stimuli are initially presented to the face superior RH. This is consistent with the prediction of a greater SE when the to-be-ignored face stimuli are projected to the RH. Once again, the validity of these interpretations is questionable given that such components typically reflect non-cognitive processes. The N2 also generated more negative amplitudes for incongruent than for the congruent condition over the frontal sites (see Figure 3.65). This finding can also be interpreted in terms of attentional resources, in that the greater negativity for incongruent condition over the frontal regions may indicate a greater attentional resource allocation for the more difficult condition (i.e.,
incongruent condition). As in Experiments 1 and 3, the congruent condition generated greater P3 amplitudes than the incongruent condition. This suggests that P3 amplitudes reflect the ease of processing of the Stroop and Stroop-like stimuli. Unlike Experiment 1, and consistent with Experiment 3, the SE in Experiment 4 was essentially invariable to laterality factors. Consistent with all three experiments, P3 latency did not show any effect with respect to the congruency condition. As indicated by Verleger (1997), the P3 latency may not be an appropriate indicator for the chronometry of different stages of information processing (i.e., in the case of Stroop paradigm related to the locus of the SE). A lack of P3 latency shifts for the incongruent versus congruent condition may indicate that the SE occurred after the onset of the P3 peak or that the SE is distributed across several stages of information processing. Surprisingly, we did not find any hemispheric asymmetries for the P3 with respect to the SE, even though the behavioral data indicated a greater SE when to-be-ignored faces were projected to the LH and the target words were lateralized to the RH.
CHAPTER IV

GENERAL DISCUSSION

Behavioral Findings

Stroop effects (SEs). In all four experiments the SE was found, as shown in Table 4.1. The greatest SE was observed for the face/word Stroop analog with word target and the smallest SE was observed for the lateralized Stroop stimuli with delayed matching response. These findings are somewhat surprising, since neither the relative speed of processing model nor the automaticity model predicted a SE for the lateralized Stroop task with delayed matching response or for face/word Stroop analog with word target.

As a reminder, the relative speed of processing model states that the faster process (e.g., word reading) interferes with the slower one (e.g., color naming) but the reverse is not possible. In all four Stroop-type of tasks two processes are involved: processing the target (i.e., color identification in Experiments 1 and 2, face identification in Experiment 3, and word identification in Experiment 4) and processing the distractor (i.e., word identification in Experiments 1, 2, and 3, and face identification in Experiment 4). According to the relative speed of processing model, the two processes are carried out in parallel with the processing of the distractor being executed faster than that of the target. In this view, the SE is explained as the extra amount of time needed to suppress the distractor-related response (MacLeod, 1991).
Table 4.1
SE (RT advantage for congruent versus incongruent trials) and hemispheric asymmetries for Experiments 1 to 4.

<table>
<thead>
<tr>
<th>Task</th>
<th>SE (msec)</th>
<th>Hemispheric asymmetries in the SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateralized Stroop task</td>
<td>36</td>
<td>No</td>
</tr>
<tr>
<td>Lateralized Stroop task - delayed matching response</td>
<td>14</td>
<td>No</td>
</tr>
<tr>
<td>Face/word Stroop analog - face target</td>
<td>30</td>
<td>Yes (Bilateral)</td>
</tr>
<tr>
<td>Face/word Stroop analog - word target</td>
<td>57</td>
<td>Yes (Bilateral)</td>
</tr>
</tbody>
</table>

According to the automaticity model, automatic processes are more rapid by virtue of their being more practiced. In addition, automatic processes are executed in an all-or-none fashion, they are independent of processing strategies, they are not reliant on cognitive resources (MacLeod & Dunbar, 1988), and they are more difficult to unlearn (Shiffrin, 1996). Conversely, there are so called “controlled” processes, which are slower and dependent on processing strategies and cognitive resources (MacLeod & Dunbar, 1988). According to the automaticity model, the faster, automatic processing of the distractor interferes with the slower, less automatic processing of the target, thus generating a SE. While the relative speed of processing model does not explain why we cannot inhibit the processing of the word, the automaticity model accounts for a SE by the very nature that the processing of words is obligatory or automatic.
What follows is a review of the SE findings from each experiment as they relate to the predictions of these two models. The finding of a SE with non-integrated lateralized Stroop stimuli (i.e., Experiment 1) has been replicated numerous times (see the Introduction for a review of lateralized Stroop studies), and it is in accordance with both models: word reading is faster/more automatic than color naming. Thus, both models predict the findings from Experiment 1.

The occurrence of the SE with a delayed color matching response in Experiment 2 was somewhat surprising. Certainly, the relative speed of processing model would not predict a SE for delayed matching responses since the delay ensures full processing of both the target and the distractor by the time a response is required. The automaticity model, is unable to account for the SE for a delayed matching response in that it lacks any elaboration of what happens to memory traces of the automatic and controlled processes. Ergo, neither the relative speed of processing model nor the automaticity model adequately explain or predict the SE with delayed color matching response.

The finding of a SE in the face/word Stroop analog task with face target (Experiment 3) was expected. This finding is in accordance with findings of SEs from picture-word interference tasks (for review see MacLeod, 1991) as well as face-name interference (Young, Ellis, Flude, McWeeny, & Hay, 1986). Most research with the picture-word interference tasks demonstrated that the words interfered with picture naming. These findings are in agreement with the relative speed of processing and automaticity models, presuming that word reading is faster and more automatic than picture naming. However, a pilot study I conducted, using targets but no distractors,
indicated that face identification tended to be faster than word identification. In this case, the relative speed of processing model cannot explain the findings in Experiment 3, since the slower process (i.e., word reading) interfered with the faster process (i.e., face identification). The automaticity model is also unable to account for the SE in Experiment 3 if processing the faces can be considered more automatic than processing the words, as inferred from the pilot study.

Surprisingly, the greatest SE was found for the face/word Stroop analog task with the word target (Experiment 4). In contrast to this outcome, most studies with picture-word tasks have not shown that pictures interfere with word reading (MacLeod, 1991). The relative speed of processing model as well as the automaticity model can explain the SE in Experiment 4. Based on the pilot data, the faster or more automatic process of identifying faces interfered with the slower or less automatic process of identifying word.

A few studies have, however, reported that faces or line-drawings interfered with word categorization in picture-word interference tasks (Glaser & Dungelhoff, 1984; Smith & Magee, 1980; Young, Ellis, Flude, McWeeny, & Hay, 1986). In such categorization tasks, the participants were required to categorize the words or names (e.g., politicians versus entertainers) while ignoring the face/line-drawing stimuli. However, these findings are not exactly analogous to the findings from Experiment 4, since the face/word Stroop analog task with word target was basically an identification, rather than a categorization, task because there was only one exemplar from each category. It appears that in the case of highly automatized Stroop components there can be an interference effect both ways.
The combined findings from the face/word Stroop analog tasks with face target and with word target represent a challenge for the relative speed of processing as well as the automaticity model of the SE. Namely, one of the basic patterns of the Stroop task is an asymmetric one, meaning that word reading interferes with color naming, while color naming does not interfere with word reading. If the face/word Stroop analog task can be considered analogous to the Stroop task, there should be a similar asymmetry such that the word identification interferes with face identification while face identification should not interfere with word reading. Since relative speed of processing and automaticity models state that the asymmetry results from interference from the faster/more automatic processing of the distractor than for the slower, more controlled processing of the target, these models fail for the face/word Stroop analog task, since this task showed SEs with face targets as well as with word targets. Therefore, a revision of the automaticity model is proposed. If both components of the Stroop analog stimuli are processed in a highly automatized fashion, as in the face/word Stroop analog task, then the two components can interfere with each other, depending on the target/distractor selection (i.e., word target/face distractor or face target/word distractor). That is, the task requirement in the face/word Stroop analog task modulates attention in top-down fashion such that the words or the faces can interfere with each other.

**Laterality effects.** The guiding idea for all four experiments was to investigate hemispheric asymmetries and interhemispheric interactions during the performance of a lateralized Stroop or face/word Stroop analog task. The relative speed of processing model as well as the automaticity model predict that there would be greater interference
when the to-be-ignored distractors (i.e., words or faces) are projected to the respective specialized hemisphere (i.e., LH for words and RH for faces). The findings from this dissertation, however, did not support such predictions. For unilateral presentations (i.e., the target and distractor are projected to the same VF), none of the four experiments indicated any hemispheric asymmetries. In addition, in Experiment 1, there was also a lack of hemispheric asymmetries in the SE for bilateral presentations, thus supporting David's (1992) but not Weekes and Zaidel's (1996) findings. Contrary to the prediction, for Experiment 1, the SE was approximately equivalent for unilateral and bilateral presentations. Similar findings were reported by Chiarello and Maxfield (1994) in their review of studies dealing with hemispheric interference. Chiarello and Maxfield concluded that similar top-down processes are involved in the mediation of interhemispheric and intrahemispheric interference in order to produce equivalent interference.

As indicated in the review of lateralized Stroop studies, hemispheric asymmetries for the SE are not very stable or readily obtained. Previous research also suggested that the SE may be more readily observed for male than for female participants (Franzon & Hugdahl, 1986) but such findings were not supported in this dissertation. Thus, the findings from this dissertation contribute additional evidence against hemispheric asymmetries for a SE with lateralized Stroop stimuli. However, it is necessary to be aware of potential limitations of the findings from this project since behavioral data was collected in parallel with electrophysiological data. It may very well be that the concurrent recordings of the ERPs may create mental states (i.e., anxiety) which can
interfere with laterality. The lateralized Stroop task with delayed matching response may not be considered a true lateralized task, since the response delay allows for interhemispheric transfer of stimuli information, so that both hemisphere have had an adequate chance to evaluate the stimuli before a response is required. Thus, the lack of hemispheric asymmetries for Experiment 2 were expected and not surprising.

Rather surprising, and contrary to my predictions, was a lack of hemispheric asymmetries for the unilateral presentations of the face/word Stroop-like stimuli with face or word target. This finding suggests that each hemisphere can perform the face/word interference task equally well or, alternatively, the respective hemispheric superiority either for faces or for words does not play a critical role in interference within each hemisphere. However, for bilateral presentations of face/word stimuli (i.e., target and distractor projected to different hemispheres) hemispheric asymmetries were found, in which there was a smaller SE when the target was presented to the LH and the distractor to the RH than for the reverse, irrespective of whether the targets were faces or words. This finding suggests that the LH is better shielded from RH interference than vice versa. In other words, the LH is superior to the RH at inhibiting conflicting information from the contralateral hemisphere. These findings are in line with Beaumont and Dimond's (1973) assertion that the LH “controls the organization of bilateral [hemispheric] patterns of learned material” (p. 91). Their assertion has been supported by findings concerning transfer of learning between the two hemispheres (Hall, Kennelly, & Herrington, 1995). The findings from this dissertation extend the role of the LH in controlling hemispheric interactions. Thus, RVF word presentations generate a greater SE than LVF
presentations, not because of LH language superiority, but because the conflicting information from the LH can interfere more with the processing in the RH than the reverse.

An additional finding with respect to laterality effects was a greater SE for females than for males for bilateral Stroop stimulus presentations in Experiment 1. Bilateral presentations by their very nature produce interhemispheric interactions, therefore this finding is consistent with sex differences in callosal connectivity (Witelson, 1990), whereby greater callosal connectivity in females than males may account for the greater interhemispheric SE in females. However, similar findings were not replicated in the three other experiments.

**Practice effects.** Sex differences in practice effects were observed across Experiments 1, 3, and 4 such that there was an overall improvement in response times for females, but not for males. This may represent a difference in motivation or strategy between males and females. The lack of such an effect for Experiment 2 is probably due to the changes in task requirements (i.e., target matching versus target identification). Despite responding to 382 Stroop or Stroop analog stimuli which were analyzed in two blocks of trials, participants did not exhibit a decrease in the SE. This finding is in accordance with Shiffrin’s (1996) assertion that automatic processes are hard to unlearn. In other words, the number of trials in all four experiments was not enough for participants to make their color naming and face/word identification faster and more automatic such that these processes would achieve a comparable level of automaticity of target and distractor processing.
In summary, behavioral findings from this dissertation demonstrated the robustness of the SE, since it was found across different stimuli (i.e., classical Stroop stimuli as well as face/word Stroop analog stimuli) and with different response options (i.e., immediate and delayed responses), but there was frailty of hemispheric asymmetries for the SE. Consequently, the findings repudiate the relative speed of processing model and require modification of the automaticity model. The problem with the relative speed of processing model have been previously discussed. In order for the automaticity model to account for these findings, it must be modified such that in the case of the Stroop analog stimuli comprised of two components (i.e., words and faces) which can be processed in highly automatic fashion, each component can interfere with the other depending on the task demand (i.e., selection of the target and distractor). Furthermore, findings from this dissertation indicate that the hemispheric asymmetries of the SE were not readily found. The findings of hemispheric asymmetries for the SE with bilateral face/word Stroop analog stimuli indicate that the hemispheric asymmetries of interference effects may not depend upon the hemispheric superiority for the distractor processing (i.e., LH for word distractor and RH for face distractor). Instead, the findings indicate LH superiority in inhibiting interfering information from the RH than the reverse. Therefore, for bilateral presentations, there will be greater interference when any type of distractor is presented to the LH and the target to the RH than the reverse. Further research is needed in order to confirm the above proposed model and make it generalizable across other tasks.
ERP Findings

Early laterality effects. In general, the direct VF-hemisphere projections generated greater amplitudes and earlier latencies than the indirect projections. This is supported by evidence from all four experiments as well as with the findings from other researchers (Brown, Larson, & Jeeves, 1994; Hoptman, Davidson, Gudmundsson, Schreiber, & Erschler, 1996; Rugg, Kok, Barrett, & Fishler, 1986; Saron & Davidson, 1989). The greater amplitudes for direct than for indirect projections were observed for the N1 but not for the P1 component. As predicted, greater N1 amplitudes (more negative) for direct than for indirect presentations were found over both hemispheres in Experiments 1 and 2 (classical Stroop stimuli), while for Experiments 3 and 4 (face/word Stroop analog stimuli), greater N1 amplitudes for direct than for indirect presentations were generated only over the RH. The differences between N1 amplitude patterns for direct versus indirect presentations between classical Stroop stimuli and face/word Stroop analog stimuli suggest that the early laterality effects reflect different hemispheric processes contingent upon stimuli but not task characteristics. For example, similar findings were obtained in Experiments 3 and 4 even though the task requirements were diametrically opposite (i.e., attending to words versus attending to faces). Additionally, the task dependent N1 laterality effects suggest that the N1 component is not just a sensory evoked, exogenous response (i.e., dependent upon stimulus characteristics) but is also sensitive to cognitive processes and the allocation of processing resources (Schweinberger et al, 1994). This interpretation is consistent with Rugg et al.’s (1986)
Table 4.2

Interhemispheric Transfer Time (range in msec) for P1 and N1 ERP components across occipital, temporal and parietal sites for four experiments.

<table>
<thead>
<tr>
<th>Experiments</th>
<th>P1</th>
<th>N1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RH to LH</td>
<td>LH to RH</td>
</tr>
<tr>
<td>Experiment 1</td>
<td>36 - 42</td>
<td>35 - 48</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>39 - 46</td>
<td>40</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>27 - 31</td>
<td>13 - 37</td>
</tr>
<tr>
<td>Experiment 4</td>
<td>27 - 35</td>
<td>28 - 37</td>
</tr>
<tr>
<td>Average</td>
<td>35.2</td>
<td>34.7</td>
</tr>
</tbody>
</table>

assertion that the pathway asymmetries of the early ERPs depend on the processing demands of the task, while the latency delays for indirect presentations are indicative of structural differences (i.e., longer neuronal pathways for indirect presentations due to obligatory involvement of callosal fibers for ipsilateral P1 and N1 components). Earlier latencies for the P1 and N1 components for direct than for indirect projections over the occipital, temporal, and parietal sites were consistently found across all four experiment and are presented in Table 4.2. As seen from Table 4.2, for the P1 component, the IHTTs are essentially consistent across the four experiments and range from 13 to 48 msec. Average IHTTs across posterior sites (i.e., occipital, temporal and parietal sites) from the RH to the LH were approximately the same as the average IHTTs from the LH to the RH.
(i.e., 35.2 msec for R to L transfer and 34.7 msec for LH to RH transfer). Average IHTTs for the N1 component were shorter than for the P1 component ranging from 6 to 33 msec (see Table 4.2). Additionally, for the N1 component, there was an overall directional asymmetry of IHTTs such that there were shorter IHTTs from the RH to the LH (16.1 msec) than from the LH to the RH (23.4 msec). The differences in IHTTs between P1 and N1 components may be due to the involvement of different callosal fibers with different conduction velocities in the transcallosal transfer of information between homologous cortical areas for P1 and N1 generators. Evidence for faster transcallosal transfer of information from the RH to the LH than vice versa is consistent with previous research (Brown, Larson, & Jeeves, 1994; Hoptman, Davidson, Gudmundsson, Schreiber, & Erschler, 1996; Saron & Davidson, 1989). Additionally, faster RH to LH than LH to RH IHTTs is consistent with Beaumont and Diamond’s (1973) model for LH metacontrol over hemispheric interactions. Taken together, these findings contribute additional evidence that ERPs are a reliable resource for studying interhemispheric transfer (Saron & Davidson, 1989).

**Hemispheric superiority.** Even though no specific predictions were made with respect to the electrophysiological indices of hemispheric dominance, such effects were nevertheless examined. Hemispheric asymmetries were inferred from the VF-hemisphere manipulations in cases when they fit known neuropsychological facts (i.e., LH language superiority and RH superiority for face processing). Since there was no supporting evidence for hemispheric superiorities from the behavioral data, inferences made concerning hemispheric superiorities from ERP data must be carefully considered.
Rather surprisingly, the finding of overall hemispheric superiorities appeared to be more related to the VF of input than to the hemisphere being recorded. For example, in the face/word Stroop analog - face target task, unilateral LVF presentations generated greater posterior P1 amplitudes than the RVF presentations at parietal and occipital sites over both hemispheres (see Figure 3.45). This finding may have been due to the limited spatial resolution of the ERP methodology. An alternative explanation for this finding may be that the specialized hemisphere activates both hemispheres, and thus, controls interhemispheric transfer. Also surprising was the finding that hemispheric superiority was observed at early, exogenous posterior ERP components (i.e., posterior N1 and P1). This finding suggests that hemispheric asymmetries occur even in the early sensory stages of information processing. In experiments using classical Stroop stimuli (Experiment 1 and Experiment 2), a putative LH language superiority was demonstrated over the temporal site: word alone presented to the RVF (i.e., bilateral presentations) generated more negative N1 amplitudes than the word presented in the LVF. Other possible evidence for LH superiority for word processing was consistently demonstrated across experiments requiring an immediate response (Experiment 1, 3, and 4) whereby N2 amplitudes were larger when the words were presented to the LH than to the RH. Since the N2 component indicated hemispheric asymmetries of language processing irrespective of the task (i.e., word targets in Experiment 1 and 3, word distractors in Experiment 4), the N2 may indicate general linguistic processing in these tasks.

In Experiments 3 and 4 there was evidence consistent with RH superiority for face processing. Hemispheric asymmetries were observed for the early posterior N1
component such that there were larger amplitudes for face projections to the LVF (i.e., RH) than to the RVF (i.e., LH). Apparently, this hemispheric superiority effect with faces does not depend on the attentional set of the participants (i.e., word vs. face target), but may reflect face precedence in the processing of face/word Stroop analog stimuli. Contrary to the above findings, Schweinberger et al. (1994) found that laterally presented faces and words in recognition task produced sustained hemifield dependent negativity that was expressed as an increase in negativity over the directly, but not the indirectly, stimulated hemisphere, and this began as early as the N1 component. According to Schweinberger et al. (1994), a greater negativity over the hemisphere which initially received the stimuli suggests that each hemisphere can perform face and word recognition tasks (i.e., relative hemispheric specialization), and that there is greater allocation of processing resources to the directly stimulated hemisphere. The lack of a hemifield sustained negativity in this research may indicate that the hemifield dependent negativity is sensitive to stimulus and/or task demands.

Correlates of the SE. The most surprising finding in this dissertation was the very early ERP indices of the SE (i.e., dissociation between the congruent and incongruent condition). These findings were surprising in that the early exogenous components are believed to depend primarily upon sensory factors. Early SEs were found across all four experiments and were typically limited to higher order interactions that usually included sex. A consistent pattern of an early SE was obtained for face/word stimuli, but not for the classical Stroop stimuli, suggesting that the early SE may be task dependent. In Experiment 3 and 4 (i.e., face/word Stroop analog task) there was a small, but significant
early SE (i.e., main effect of condition), that was more reliable for the anterior N1/P1 than for the posterior P1/N1 components. For this early SE, the incongruent condition generated more negative amplitudes than the congruent condition. A greater negativity for incongruent conditions may indicate a greater allocation of processing and attentional resources for incongruent than for congruent conditions. Findings of early SEs are consistent with those of Miller et al. (1996) who reported effects of methylphenidate on ERPs in ADHD boys, occurring as early as the anterior N1. Such early occurrences of the SE are very puzzling and inconsistent with most models of cognition since this suggest that the brain somehow distinguishes between congruent and incongruent stimuli at a very early perceptual processing stage, before the 'cognitive' stages of processing. In general, these findings indicate that there may be top-down effects on early perceptual and/or attentional processes.

These early electrophysiological SE findings can be accommodated by Marcel’s (1983) perception model. According to Marcel, perceptual processes evolve from very early, preconscious processes to a fully conscious, experiential percept. Preconscious processing entails automatic processes of sensory analysis which produce nonconscious results and records, and so called perceptual hypotheses. It is the perceptual hypotheses which may be indicated by the early SE, since these are thought to be a canonical representations of perceptual and conceptual categories. In the nonconscious perceptual hypotheses stage, sensory analysis output are matched to different perceptual hypotheses (e.g., templates, schemas) and one is selected. Thus, perceptual hypotheses become the basis for conscious percepts. The individual becomes aware or conscious of the selected
hypothesis which is the best fit to the relevant record. Marcel states that "a conscious percept is obtained by a constructive act of fitting a perceptual hypothesis to its sensory source." (p. 245). Thus, in the performance of the Stroop task, it may be assumed that there are two separate perceptual hypotheses (i.e., one for congruent and one for incongruent stimuli) which are matched to every instance of Stroop stimuli. It may be that preconscious perceptual processing of incongruent stimuli generates a different pattern of neuronal activation than for congruent stimuli, thus producing an early SE.

With a delayed response to Stroop stimuli (Experiment 2), a SE was observed for the N2 component, where the congruent condition generated more negative N2 amplitudes than the incongruent condition. The finding of a SE for the N2 component in only one out of the four experiments indicates that this effect may be spurious or at least very unstable. Further research is needed to determine whether the SE for the N2 is false and/or task dependent (i.e., observed only with a delayed matching response).

The main focus of this dissertation project was to investigate ERP correlates of the SE. It was predicted that if present, the SE would be evident in later ERP components especially for the P3 component whereby the incongruent condition would generate greater amplitudes than the congruent condition. This hypothesis was partially supported since a SE was found for P3 amplitudes, although in an opposite direction from that predicted: across all four experiments the congruent condition generated greater P3 amplitudes than the incongruent condition. This finding was interpreted in terms of task difficulty: the easier condition (i.e., congruent) generated greater P3 amplitudes than the more difficult one (i.e., incongruent). This interpretation parallels that of West, Noaves,
and Kavcic (1996), who suggested that P3 amplitudes are an index of task difficulty: the more difficult the task, the smaller the P3 amplitude. This finding may also reflect known effects of difficulty of stimulus categorization on P3 amplitudes (Schweinberger et al., 1994): the more difficult the categorization, the lower the P3 amplitude. Greater P3 amplitudes for the congruent than for the incongruent condition found in this research were not observed in previous research (Duncan-Johnson & Koppell, 1983; Verleger, 1997; Vidal, Henry, & Grapperon, 1994). Thus, observed P3 amplitude effects may be attributable not only to the congruency/incongruency factor, but also to the stimulus characteristics (i.e., spatially separated components of the Stroop and Stroop-like stimuli) and/or to the stimulus presentation mode (i.e., lateralized presentation of the classical Stroop stimuli and face/word Stroop analog stimuli). Future research can determine which of these factors contribute to the P3 amplitude SE.

With respect to P3 latency findings, the lack of P3 latency shifts between congruent and incongruent condition, despite robust effects for RT, is consistent with previous research (Duncan-Johnson & Koppell, 1983; Verleger, 1997; Vidal, Henry, & Grapperon, 1994). Such findings imply that the SE occurs after the decision making stage (as indexed by the P3), but prior to the response execution stage. However, it may be that the P3 component is not the most suitable ERP component for examining latency shifts. As Verleger (1997) stated, P3 latency lacks the necessary sensitivity for distinguishing between stimulus and response related processes. Future research may well want to focus on other components and/or areas (e.g., component over motor
cortices). For example, Ridderinkof and van der Molen (1995) demonstrated that lateral readiness potentials recorded over motor cortices are sensitive to interference effects.

An alternative interpretation that is supported by the findings from this dissertation is that the SE is manifested across several processing stages. Given this view, the historical search for a single locus for the SE has been ill conceived. In other words, I propose that there is no particular locus of the SE, but rather, the SE is distributed across a broad range of information processing stages. The behavioral findings indicate robust SEs for all four experiments, while the electrophysiological findings indicate that the SE occurred as early as at the exogenous P1 and N1 components (i.e., preconscious perceptual processes) and as late as the N2 and P3 components (i.e., indicating higher level cognitive processes: decision making, memory updating). Consequently, the models dealing with the locus of SE, early perceptual and late cognitive models, are correct, but not exclusively. In other words, the SE can occur across several stages of information processing. However, this interpretation must be taken cautiously since there was no definite pattern of SE for early anterior N1 and P1 as well as for early posterior P1 and N1 components across all four experiments.

One of the objectives of this dissertation was to investigate the overlap of P3 and N4 components. Contrary to the prediction, the delayed matching response to the classical Stroop stimuli did not reveal a visible N4 component. This finding indicates that Stroop stimuli do not produce an N4 component similar to that produced by semantic incongruency tasks. A possible explanation is that the N4 component may be related to expectancy effects across successive stimuli. The N4 is present in tasks where a stimulus
is incongruous relative to the preceding stimulus or stimuli. In this view, the N4 depends on temporal memory factors that are absent during simultaneous presentations of incongruent Stroop stimuli. In future studies, the temporal expectancy hypothesis can be tested by manipulating stimulus onset asynchronies of the two components of the Stroop and Stroop-like stimuli.

Electrophysiologically, sex differences were found in all experiments. However, results across all four experiments indicated that such sex effects were typically embedded in higher order interactions. In all four experiments, sex effects were found for the early posterior P1/N1 complex, albeit, interacting with other experimental variables (i.e., Condition, Presentation, Visual field of the word presentation, Site, and/or Hemifield), and not in a consistent fashion. Idiosyncratic Sex effects were also present for other ERP components. The finding of sex effects interacting with other experimental variables, often in complex ways, is consistent with sex differences found in behavioral laterality studies (Zaidel, Aboitiz, Clarke, Kaiser, & Matteson, 1995). The lack of consistent sex effects from this dissertation preclude any reasonable conclusions regarding electrophysiological differences between males and females.

Comparison of behavioral and ERP lateralized SE findings. One would expect a high degree of consistency between behavioral and electrophysiological findings. Therefore, it was predicted that the ERP findings would show similar laterality patterns as the behavioral findings. However, inconsistencies were found. In Experiment 1, no behavioral laterality effects were found. ERPs, however, indicated hemispheric asymmetries in the SE for unilateral presentations: there was a greater P3 SE over the
language specialized LH than over the RH (see Figure 3.19). This finding is consistent with the prediction that classical Stroop stimuli exhibit greater interference when projected to the LH. Also in Experiment 1, P3 amplitudes were reduced to a greater extent for incongruent stimuli over the LH temporal site than over the RH temporal site, thus, the LH showed greater sensitivity to the SE than the RH (see Figure 3.19). With the delayed matching response to classical Stroop stimuli (Experiment 2), neither behavioral nor electrophysiological data showed any laterality effects. For the face/word Stroop analog task, it was expected that the laterality of the SE would be related to hemispheric superiority for the distractor (i.e., LH superiority for the word distractors and RH superiority for the face distractors). Surprisingly, and contrary to what was predicted, ERPs did not indicate any hemispheric asymmetries, while behaviorally, the LH showed better shielding of incongruent information from the RH than vice versa. Rugg et al. (1986) suggested that the lack of the hemispheric asymmetries in ERP studies may be due to the lack of effective tasks (i.e., lateralized flash, simple geometrical figures, letters, four letter nouns presentations) in inducing differential hemispheric engagement. For this dissertation face/word Stroop analog stimuli were created based upon knowledge of LH word superiority and RH superiority for face processing. Even with this task, which most likely differentially activated both hemispheres, the electrophysiological evidence for lateralized SEs was lacking. Taken together, the behavioral and electrophysiological findings suggest that laterality effects for the SE are not robust and are very sensitive to stimulus and task demands.
Overall, electrophysiological findings are consistent with other research regarding the early laterality effects generated by direct versus indirect lateral presentations and regarding hemispheric superiority for word and face processing. ERP findings from this dissertation did not provide conclusive evidence with respect to the electrophysiological differences between males and females. The ERP finding indicate, however, that the Stroop-like tasks do not generate an N4 component due to incongruency between two components of the Stroop and Stroop-like stimuli. The principal finding related to ERPs is that the SE appears to be distributed across a wide range of information processing stages.

Conclusion

In summary, this dissertation provided evidence for three major conclusions: (a) contrary to the prediction of the automaticity model that more automatic process interferes with less automatic one and not vice versa, two types of stimuli (faces and words) processed in high automatic fashion can mutually interfere with each other when presented in Stroop-like fashion, and this suggests the importance of top-down influences on the SE, (b) the LH controls the pattern of hemispheric interactions in the performance of the Stroop-like task such that the LH is less susceptible to interference from the RH than vice versa; and (c) the search for the “holy grail” of the SE may be over. The SE appears to be distributed across many stages of information processing, from early sensory analysis to later decision making and response selection stages. Future studies are needed to verify these conclusions, and to further clarify the nature of the SE at each successive stage of processing.
REFERENCES


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