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INTERFERENCE BETWEEN STIMULUS AND RESPONSE PROCESSING DEMANDS WITHIN A CEREBRAL HEMISPHERE

A Dissertation Presented

By

JOANNE GREEN

Submitted to the Graduate School of the
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Psychology

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ABSTRACT

Interference Between Stimulus and Response Processing Demands Within a Cerebral Hemisphere

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Directed by: Arnold D. Well

The present research was designed to examine the kind of interaction that occurs between stimulus and response processing demands within a cerebral hemisphere, with particular interest in whether interference between such demands occurs. Four experiments were performed, in which subjects used a manual response to indicate whether a pair of stimuli, presented in the left, right, or center visual field, were the same or different, according to specified criteria. The presence of interference was inferred if response time was slowed when the stimulus was projected to the hemisphere controlling the response. Interference was observed in performance of a visuospatial, physical identity letter matching task, using either a bimanual or unimanual choice response. Interference was also observed in performance of a verbal, letter name matching task, using a unimanual choice response, but not in performance of a verbal,

concept matching task using the same response. In cases where interference occurred, it tended to be greater in the hemisphere specialized for the stimulus processing. It was concluded that interference, rather than facilitation, sometimes occurs when stimulus and response processing demands are confined within one hemisphere. Such interference may be masked, or may be less influential, in conditions where performance is highly variable and/or where attentional biases strongly favor a particular visual field. Reaction time studies of hemispheric specialization need carefully consider such effects in interpreting their results.

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CHAPTER I

INTRODUCTION

The largest structure of the human brain, the cerebrum, is composed of two physically distinct halves, known as the cerebral hemispheres. Much effort has been devoted to investigations of whether the two hemispheres differ in function, and how they interact. Historically, the left hemisphere was associated with many of the major cerebral functions, most importantly, speech and verbal processes. Right hemisphere functions remained less clear, and some believed it to be merely an extra organ which might be used in cases of functional failure of the left hemisphere (Henschen, 1926; Strong and Elwyn, 1943). More recent research on hemispheric function has focused on two distinct, but related ideas. The first idea is that of hemispheric specialization--the idea that each hemisphere has certain functions which it performs more efficiently, with the left hemisphere showing superiority at verbal tasks, and the right at spatial tasks. The second idea is that of a "double brain"--the idea that a task may be performed more efficiently if the processing demands are divided between the two hemispheres, rather than being confined to a single hemisphere. Since both of these ideas are important to understanding the present research, each will be considered separately, after a brief discussion of methodology.

CHAPTER II

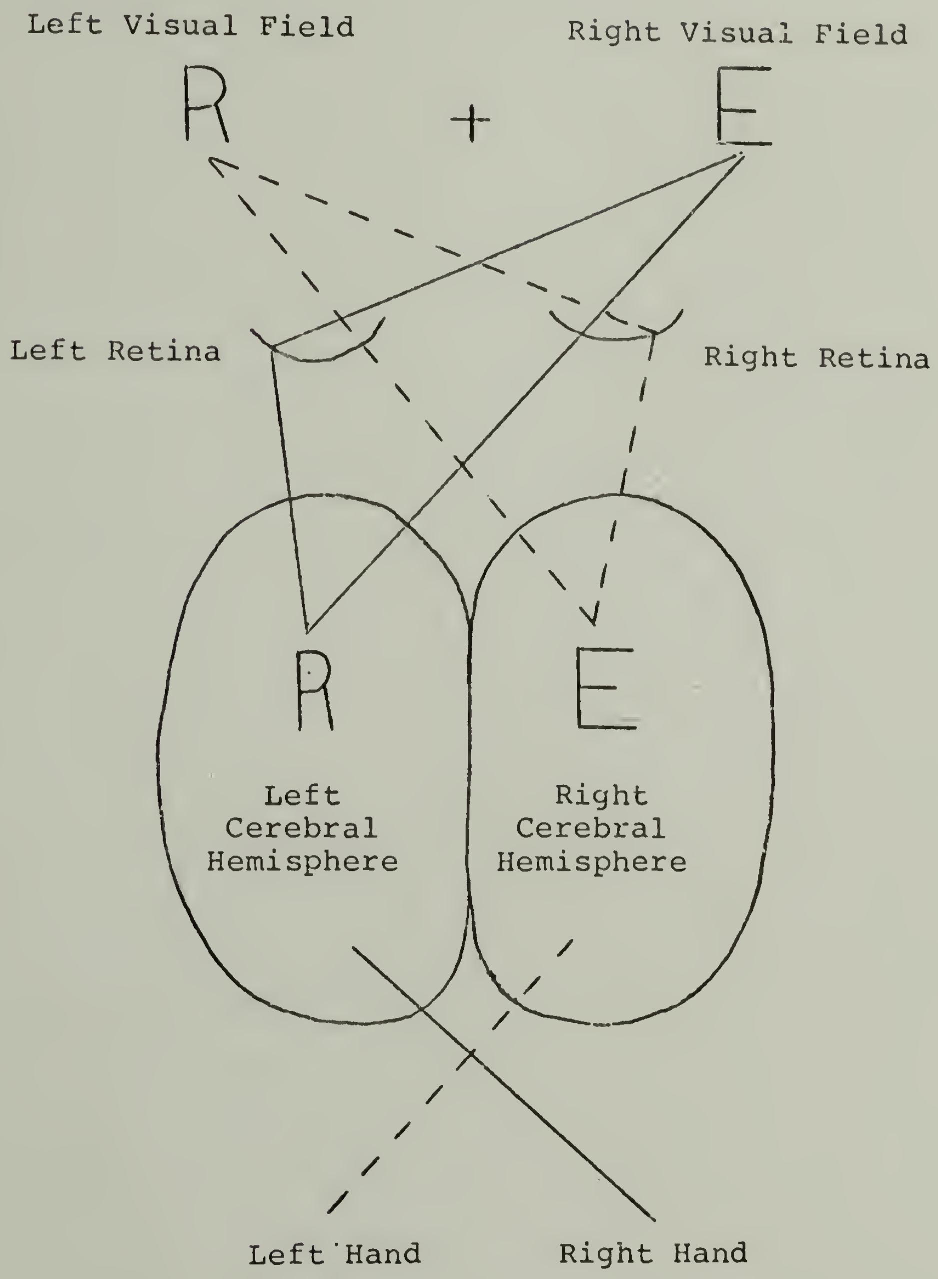
REVIEW OF RELEVANT LITERATURE

General Methodology

The research to be discussed here involves presentation of stimuli in the visual modality. It takes advantage of the fact that when an individual is fixating on a given point in space, a stimulus in the right visual field is initially received by the left hemisphere, and a stimulus in the left visual field is initially received by the right hemisphere. As Figure 1 indicates, although a stimulus in either visual field is projected to both the right and left retinas , there is a crossing of the nasal retino-cortical pathways, leading to a reception of visual information by the hemisphere contralateral to the visual field in which it occurred. Most hemispheric studies in the visual modality instruct subjects to fixate on a central point, then present stimuli one to four degrees to the left and/or right of fixation. Stimuli are presented for no more than 150 msec, which minimizes the possibility that the eyes can be moved to the stimulus during its presentation. Where possible, eye movements are monitored to insure central fixation, and to better control the hemispheric projections.

The bulk of the literature focuses on stimulus pro-

Figure 1. A schematic diagram of visual afferent and manual efferent connections to the cerebral hemispheres



cessing by the hemispheres. By presenting stimuli in the left and/or right visual fields, it is possible to initially project stimuli to a specific hemisphere, or hemispheres. In studies of specialization, it is assumed that if a given hemisphere is specialized at performing the stimulus processing necessary for a given task, the subject will respond more quickly and/or more accurately when the stimulus is projected to that hemisphere. Thus, left hemisphere specialization is inferred when there is a performance advantage for stimuli projected from the right visual field. Right hemisphere specialization is inferred when there is a performance advantage for stimuli projected from the left visual field.

One factor which is taken into consideration in hemispheric studies is the handedness of the subjects being tested. There is considerable evidence that specialization is greater, and more consistent, within the right-handed population, as compared to the left-handed population (Zangwill, 1960). To better control for individual differences, hemispheric studies generally test strongly right-handed subjects.

Obviously, the procedures described above can provide us with valid data about hemispheric functioning only if the response used as the dependent measure does not bias or confound the results. For example, in reaction time studies, a faster reaction time for stimuli projected from the left visual field could occur because the right hemisphere is specialized for stimulus processing, and/or because the response can be more efficiently produced when the stimuli are projected from that visual field. Later discussion will elaborate on the nature of possible response effects, and will indicate that they have not been adequately examined or considered in interpreting studies of hemispheric functioning.

Hemispheric Specialization

There are three basic sources of ideas concerning hemispheric specialization: (1) the study of so-called "split brain" individuals who, for medical reasons, have undergone operations severing the direct hemispheric connections; (2) the study of individuals who have experienced either brain damage or have undergone hemispherectomy, and (3) the laboratory study of the behaviors of normal individuals under conditions in which an attempt is made to control the hemispheric projection of the stimuli, as described in the previous section. Since the present research involves the study of hemispheric functioning using normal individuals as subjects, the discussion will be confined largely to this literature. Primary emphasis is placed on evidence that the left hemisphere is specialized in the use of verbal processes and verbal representations, or where analytic processing is required, while the right hemisphere is specialized in the use of visuospatial operations and representations, or where holistic processing is required. To a large extent, the methodology, findings, and theory in this literature are consistent with that concerning split-brain or brain-damaged individuals. The reader is referred to works by Gazzaniga (1970), Nebes (1974), and Kinsbourne and Smith (1974) for recent summaries of split brain research, and to Milner (1965) for information derived from the study of brain-damaged individuals.

A number of studies have found a left hemisphere advantage for tasks supposedly involving the use of verbal representations, and a right hemisphere advantage for tasks involving the use of visuo-spatial representations. One particularly well-designed study is by Gross (1972). She tested right-handed subjects with a simultaneous comparison task which, in one condition, required subjects to judge two three-letter words as the same or different in conceptual category, and, in another condition, to judge whether two sixteen-cell matrices were the same or different according to which of one to three cells were blackened. In the conceptual matching task, there was a 30 msec advantage for stimulus presentations in the right visual field. In the matrix matching task, the opposite was true, though the difference between visual fields was only 18 msec. These results suggest that there is a left hemisphere superiority for a verbal task, such as concept matching, and a right hemisphere superiority for a visuospatial task, such as matrix matching.

Numerous studies have pointed out that the relative efficiencies of the left and right hemispheres are not determined by whether the stimulus pattern is a word or a visual pattern, but rather by the processing strategy best suited for a given task. Klatzky and Atkinson (1971) used a sequential comparison task, in which subjects had to memorize a set of letters and then indicate whether a test stimulus presented in the right or left visual field matched any letter in the memorized set. Where the test stimulus was a letter, which is a verbal symbol, but which could be visuospatially matched with the memorized set, there was a right hemisphere advantage. Where the test stimulus was a picture, whose first letter had to be matched to the memorized set, there was a left hemisphere advantage.

The importance of the processing strategy actually used by the subject, rather than the nature of the stimulus material, is also clearly pointed out in several studies examining right hemisphere function. A right hemisphere advantage is usually seen in tasks involving the identification or comparisons of line slants (Atkinson and Egeth, 1973, Berlucchi, 1973; Kimura, 1974), which can be reasonably described as visuospatial tasks. However, White (1971) found a left hemisphere superiority for the identification of line slant. Kimura and Durnford (1974) point out that verbal mediation was possible in White's study, since only three types of lines were used--vertical, horizontal, and oblique. This might explain why there appeared to be an advantage for the verbal, left hemisphere. Berlucchi (1973) found that the right hemisphere advantage appeared and increased with increasing number of line slants, presumably because verbal mediation became less possible.

The above studies suggest that left hemisphere presentation of stimuli may yield better performance where verbal processing mediates, or is required. Right hemisphere presentation of stimuli may be better where visuospatial processing is more useful. A second and closely related line of evidence suggests that the left hemisphere may be more efficient where serial or analytic processing is required, while the right hemisphere is better at holistic, or parallel types of processing. Cohen (1973) required subjects to judge whether a set of items was all the same, or whether one "different" item was included. She looked at reaction times as a function of set size, and as a function of the kinds of stimulus items, either letters or shapes. When the stimuli were letters, she found that, for stimulus sets projected to the left hemisphere, reaction time increased with set size, while for the right hemisphere, reaction time decreased with set size. When the stimuli were shapes, there were no significant set size effects for either the left or right hemispheres. Cohen concluded that letter sets projected to the left hemisphere are processed serially, thus causing the increase in reaction time with set size. However, Cohen argued that the processing of letter sets projected to the right hemisphere, or shape sets projected to either hemisphere could be better described as "parallel" processing, in that there was no increase in reaction time with set size.

Although Cohen's study is suggestive of a processing difference between the hemispheres, there are several problems in interpreting the data. First of all, her interpretation of reaction times to letter sets projected to the right hemisphere is somewhat confusing. She observed a decrease in reaction time as set size increased. A constancy, or slight increase, in reaction time with set size increase is the more usual situation from which parallel processing is inferred (Egeth, 1966). It is therefore not clear whether Cohen obtained valid evidence of parallel processing of letter sets by the right hemisphere. Secondly, it is not clear whether the distinction between serial (analytic) versus parallel (holistic) processing requirements is independent of the distinction between verbal and visuospatial processing requirements. The serial-parallel processing differences were seen when letters were the stimuli, but not when shapes were the stimuli. Cohen (1973) concluded that "hemispheric differences in serial versus parallel processing are limited to tasks like the matching of alphanumeric stimuli or words, which can be performed either verbally or visuospatially. The serial versus parallel processing difference is a concomitant of hemispheric predilection for nominal versus physical analysis" (p. 355).

However, a study by Patterson and Bradshaw (1975), using stylized line drawings of faces as stimuli, indicates that the left hemisphere may be better than the right where processing is likely to be serial-analytic, though not necessarily verbal. The right hemisphere is generally faster at matching faces (Geffen, Bradshaw, and Wallace, 1971; Rizzolati, Umilta, and Berlucchi, 1971), presumably because they are matched visuospatially. Patterson and Bradshow measured reaction time for matching line drawings of faces to a memorized standard face. In an "easy" discrimination condition, where a "different" test face differed from the standard by several obvious features, the expected right hemisphere reaction time advantage was observed. However, when the discrimination was made more difficult, by having the "difficult" test faces contrast from the standard on only one feature, a left hemisphere reaction time advantage appeared. Patterson and Bradshaw suggest that where the discrimination is easy, a holistic matching strategy may be used to compare the test face to the standard, and that the right hemisphere is better at holistic processing. They argue that difficult discrimination tasks require more analytic processing, which is more efficiently done by the left hemisphere. These results lend further credence to the holistic-analytic distinction between the hemispheres, though it is still possible that verbal mediation of the difficult discrimination task was responsible for the left hemisphere advantage.

A variety of other distinctions between left and right hemisphere processing have been made, and are reviewed in Dimond and Beaumont (1972). However, even assuming that such distinctions are valid, the exact nature of the specialization involved still remains a matter for speculation. A difference between the hemispheres for a given task could reflect what might be called "relative specialization"--each hemisphere can do the task, but one hemisphere is relatively better, or more efficient, at doing the task, thus yielding a reaction time advantage. Alternately, there could be "absolute specialization"--the right hemisphere _only_ could do visual code comparisons, and the left hemisphere _only_ could do verbal code comparisons. According to the latter explanation, the increase in reaction time in Gross' study for a matrix pair presented to the left hemisphere reflects callosal crossing time--extra time associated with the transfer of information via the corpus callosum to the hemisphere specialized for the kind of processing required. Most experimental studies are unable to rule out either of these two explanations for reaction time differences.

In discussing visual studies of hemispheric specialization, it is also important to note that several writers have argued that hemispheric specialization is not the factor primarily responsible for the observed differences between visual fields. White (1969) surveys "laterality studies of perception," most of which used accuracy measures as the dependent variable, and blocked the field of stimulus presentation. White argues that the differences between visual fields reported by many of these studies can be explained by factors other than that of hemispheric specialization. In particular, he suggests that the right visual field advantage obtained with unilateral presentation of verbal material can be explained in terms of a "postexposural trace-scanning mechanism," which scans from the point of fixation to the right, as in reading, thus favoring recognition of stimuli in the right visual field. Although this notion is a likely explanation of some of the studies prior to 1970, it seems to predict a consistent right visual field advantage for conditions of unilateral presentation. Previous discussion has indicated that a left visual field advantage has been observed for certain tasks. Furthermore, when different types of stimuli and tasks are presented together within an experimental session, differences in the visual fields seem to reflect hemispheric specialization for processing demands, rather than scanning strategies.

Another possible explanation for the differences between performance as a function of visual fields is suggested by Kinsbourne (1970, 1973). He suggests that activity in one hemisphere biases attention to the contralateral visual field, and that this biasing of attention is responsible for faster, or more accurate, responses for stimuli in that visual field. For example, he presents evidence that the detection of a gap is more accurately performed for stimuli in the right visual field when the subject is concurrently vocalizing, but not otherwise. The activation of the left hemisphere induced by verbalization supposedly biases attention toward the right, contralateral visual field.

Kinsbourne's notion is interesting, but seems most applicable to studies where processing demands are consistently similar for a period of time, and thus likely to differentially activate the hemispheres and to bias attention. Attentional bias alone cannot account for differences between the visual fields in studies where processing demands vary within an experimental session (Cohen, 1972; Geffen, Bradshaw, and Nettleton, 1972).

It is hoped that this review has familiarized the reader with the study of hemispheric specialization in normal subjects, including its methodology, results, and some of the problems associated with interpreting these results. It will be recalled that a second idea about hemispheric functioning is that of the "double brain." The research associated with this idea has developed largely independently of studies directed at hemispheric specialization. The implications of this research for studies of hemispheric specialization have not been carefully considered. Upcoming discussion will attempt to make these implications clearer, particularly as they are the basis for the present research.

The Double Brain

The idea that the two hemispheres may operate, to some extent, as two independent brains, to increase overall processing capacity, is most elaborately described in Dimond's book The Double Brain (1972). Dimond suggests that the operation of the two hemispheres is analogous to the operation of "two computors sitting side by side, each interacting with the world, providing a surface on which information can be received, each proceeding with analysis of the information and checking off its functions against the other, ultimately linking and cross-comparing the products" (p. 59). The double brain notion as described by Dimond implies that the brain can work more efficiently if the work load is divided between the hemispheres, rather than being performed by one hemisphere alone.

Dimond reports several studies in support of this notion. In one (Dimond, 1970), subjects were presented with an arrow pointing to the left or to the right in the left or right visual field, and were told to indicate the direction of the arrow by responding with that hand. On most trials a single arrow was presented, but occasionally, two arrows pointing in opposite directions were presented, and subjects were to respond with both hands. On the double stimulus trials, reaction times were 100 msec longer if the two stimuli were in the same visual field than if one was in each visual field. In a second experiment requiring a more complex judgment (Dimond, 1971), two four-letter words were flashed in either the same visual field or in different visual fields. The number of words that could be correctly reported was greater if the words were flashed to different visual fields. In a third study (Dimond and Beaumont, 1972), subjects were to judge whether two symmetrical half-figures matched one another. When both figures were presented in one visual field, performance was better in the left than in the right visual field, as would be expected if the right hemisphere is better at holistic matching tasks. However, performance was best when the figures were presented in different visual fields.

Davis and Schmit (1973) report a similar effect for a simultaneous letter matching in which subjects had to judge two letters as being the same or different in name. They presented the letters either both in the same visual field, or one in each visual field. They found that, overall, reaction times were 44 msec faster when the pair members were presented bilaterally, rather than unilaterally.

Dimond concludes that, "these experiments suggest that the processes of perception are relatively timeconsuming, and an advantage is to be gained where use can be made of the double interface of the brain" (p. 62). Both the methodology used (Dimond and Beaumont, 1972, pp. 57-8) and the control experiments performed argue against the possibility that the effects described above can be explained in terms of the retinal position of stimuli, or eye of stimulation. There is, however, a greater possibility that with unilateral presentation of two stimuli, some sort of lateral inhibition or masking operates to produce longer reaction times.

Fortunately, other studies using paradigms dissimilar from that used by Dimond also produce results that provide converging sources of evidence for the double brain notion. Geffen, Bradshaw and Nettleton (1973) report a study in which the demands of a secondary task determined the visual field advantage seen in the primary task. In the primary task subjects were presented with single digits which occurred randomly in the right or left visual field. They were instructed to respond vocally upon the appearance of certain, specified digits. They also performed two types of auditory secondary tasks--either a musical task, which was likely to occupy the right hemisphere (Kimura, 1961), or a verbal task, which was designed to occupy the left hemisphere.

When the primary task was performed alone, a right visual field reaction time advantage was seen, as might be expected, since the left hemisphere has greater control over verbal output. This advantage remained when the secondary task was musical. However, when the secondary task was verbal, a left visual field advantage for the primary digit detection task appeared. These results suggest that the hemisphere not occupied with the secondary task was better at performing the primary task, and are consistent with the idea of a double brain.

Several studies have also reported interference between responses controlled by one hemisphere (Hicks, Provenzano, and Rybstein, 1971, in press; Hicks, 1971, in press; Kinsbourne and Cooke, 1971). For example, Hicks (1971, in press) found that concurrent verbalization during performance of a dowel balancing task produced a decrement in right hand dowel balancing performance, but not in left hand dowel balancing. He suggested "that concurrent activities programmed within the same cerebral hemisphere can compete with each other more than those programmed within separate hemispheres," and suggested that interference between response execution processes may be responsible for the observed effects.

A final source of support for the notion of a double brain is provided by certain interactions between stimulus and response processing which are suggested in several studies that were initially designed to examine hemispheric specialization. These studies link the two areas of research, and provide a major rationale for the present research.

CHAPTER III

RATIONALE FOR THE PRESENT RESEARCH

The previous discussion has reviewed two related sets of ideas concerning the functions and interactions of the cerebral hemispheres. The first set of ideas focuses on the notion of hemispheric specialization. There is evidence from a variety of sources that, in most individuals, the left hemisphere is specialized for verbal, or analytic, processing, and the right hemisphere is specialized for spatial, or holistic, processing. A second set of ideas views the hemispheres as a sort of double brain, which work together to share the information processing load, and to increase total cerebral efficiency. As was previously mentioned, the two approaches have developed rather independently, and their implications for one another have not been carefully considered or examined.

There are, however, several studies in the literature on hemispheric specialization which seem to require both sets of ideas in order to explain their results. In examining response effects in her reaction time study of hemispheric specialization, Gross (1972) noted that the left hand, which is controlled primarily by the right hemisphere (Meyers, 1962), was faster for the verbal, left hemisphere task. The right hand, which is controlled primarily by the left hemisphere, was faster for the spatial, right hemisphere task. Gross notes that similar effects were observed by Klatsky and Atkinson (1971), who suggested that, "possibly, limitations in the processing capacity of the comparison-performing hemisphere requires the other hemisphere to monitor the comparisons and initiate the response" (p. 338).

Although the patterns described above were not significant, they are important in several related respects. First, they are consistent with the idea of a double brain--when one hemisphere is occupied with stimulus processing, the other seems to be more efficient at producing the response. They suggest that, to some extent, each hemisphere may have independent processing resources which cannot be shared with the other hemisphere. Secondly, they stress that response demands can modulate the relative efficiencies of the two hemispheres for stimulus processing. Failure to control for response biases may explain why certain studies of hemispheric specialization (Egeth and Epstein, 1972; Lefton and Haber, 1972) have been unable to replicate the findings of other, better controlled studies (Geffen, Bradshaw, and Nettleton, 1972).

Thirdly, and most importantly, the results of Gross are of interest because they imply an interaction between stimulus and response processing demands which is contrary to that assumed in most studies of hemispheric specialization. Several studies (Berlucchi, Heron, Hyman, Rizzolati, and Umilta, 1971; Bradshaw and Perriment, 1970) have demonstrated what will be called a "facilitative interaction" between stimulus and response processing--performance is better if one hemisphere both receives the stimulus and controls the response. In line with these findings, it is usually assumed that response control by the hemisphere specialized for a task will enhance reaction time differences between the visual fields which are indicative of that specialization. If differences are not found under such conditions, it is assumed that there is a lack of hemispheric specialization. In fact, interference between stimulus and response processing may be confounding the evidence for hemispheric specialization.

Thus, the possibility of interference between stimulus and response processing within a hemisphere is not only an interesting phenomenon in itself, but also has critical implications for reaction time studies of hemispheric specialization. Unfortunately, it remains unclear under what conditions an interference interaction versus a facilitative interaction will appear. In particular, interference between stimulus and response processing, though suggested by several studies, has not been either systematically demonstrated or examined.

The present research focused on examining the kind of intra-hemispheric interaction that occurred between stimulus and response processing demands in certain carefully chosen conditions. Experiment 1 established the presence of a significant interference interaction in conditions designed to optimize its appearance. Experiments 2, 3 and 4 varied the stimulus and response processing demands to examine the generalizability of the interaction observed in Experiment 1. For present purposes, the presence of an interference interaction was inferred when performance was slower and/or less accurate when the stimulus was projected to the hemisphere controlling the response. The presence of a facilitative interaction was inferred when performance was faster and/or more accurate when the stimulus was projected to the hemisphere controlling the response.

CHAPTER IV

EXPERIMENT 1

Introduction

Experiment 1 was designed to optimize the possibility that interactions between stimulus and response processing demands could be clearly observed. Primary interest was in establishing conditions that would allow an interference interaction to appear, if indeed this were a significant phenomenon.

Subjects were presented with pairs of upper case letters and were required to judge whether the two letters were physically identical or not. This task was chosen for several reasons. First, studies which have observed a reaction time advantage for stimuli ipsilateral to the responding hand have made relatively simple stimulus processing demands, such as dot detection or localization. In contrast, studies which have reported the opposite effect, i.e., an advantage for stimuli contralateral to the responding hand, involved relatively more difficult tasks, such as the comparison of simultaneously presented letters. Since the difficulty of the task may be important to obtaining the latter effect, a simultaneous comparison task was chosen for Experiment 1.

Secondly, this task usually produces fast, stable performance after relatively little practice. Interaction effects may appear more clearly in conditions where performance is rapid, but relatively stable.

Third, several studies (Cohen, 1972; Geffen, Bradshaw, and Nettleton, 1972) have reported a right hemisphere advantage for a physical identify letter matching task, which is consistent with the idea that the task is done through use of visual codes of the letters (Posner, Boies, Eichelman, and Taylor, 1969). Use of this task thus allows one to examine how interactions between stimulus and response processing influence reaction time patterns in a task for which one hemisphere is specialized.

To indicate their judgment, subjects were required to use a unimanual choice response, in which the index finger was used to indicate "match" (physical identity) and the middle finger was used to indicate "mismatch" (lack of physical identity). They were tested during two sessions, using a different hand for each session. This response was chosen because it requires fine finger movements within one hand, which makes it likely that the hemisphere contralateral to the hand largely controls the response (Myers, 1962). If interaction effects need time to stabilize, the use of a single hand for response throughout a given testing session would allow for such stabilization, and thus might facilitate the appearance of such effects. Furthermore, it was possible to make a controlled comparison within each subject of the interaction effects associated with response by each hand.

There were several patterns of results that would have been of interest. For the present purposes, a few of the more interesting are as follows: (1) there could be an overall right hemisphere advantage for the task, unmodulated by the responding hand. This result would be consistent with other studies of this task, and would also suggest that there was no significant interaction between stimulus and response processing demands. (2) There could be an overall right hemisphere advantage, with this effect being significantly greater when the left hand was responding. This result would suggest that there was reaction time facilitation when the hemisphere receiving the stimulus also controlled the response. When the left hand was used, this facilitation would increase the right hemisphere advantage associated with specialization. (3) There could be a right hemisphere advantage, but exactly the opposite interaction effect as that described in prediction number two. The right hemisphere advantage could be significantly greater when the right hand was controlling the response, or might appear only when the right hand controlled the response. This would support the notion that there was interference when the stimulus was projected to the hemisphere controlling the response. (4) There could be no overall reaction time advantage for either hemisphere, but a significant visual field by responding hand interaction of the following nature. When the right hand was used, reaction times are faster for stimuli in the left visual field, and when the left hand is used, reaction times for stimuli in the right visual field are faster. This result would clearly suggest that, in these experimental conditions, there was an interference interaction between stimulus and response processing, such that reaction times were slowed when the stimulus was projected to the hemisphere controlling the response. Results fulfilling prediction number four would suggest that this interference was overriding the effects of hemispheric specialization for stimulus processing.

Method

Subjects. 17 University of Massachusetts undergraduates were tested, 9 females and 8 males. All subjects were right-handed individuals, both of whose parents were also right-handed. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to insure that subjects were strongly right-handed. All subjects had good vision, either uncorrected or corrected by eyeglasses which they wore during testing. Subjects who wore contact lenses were not used because slippage of the lens disrupts fixation. All subjects were uninformed as to the purpose of the experiment, and received some psychology course credit for their participation.

Apparatus. A Hewlett Packard 2114B computer was used to produce stimulus tapes, read the stimulus tapes for each trial block, direct the plotting of the appropriate stimuli on a Hewlett Packard 1300A X-Y cathode ray oscilloscope, control all interval timing, and record reaction times. The subject sat at a table before the oscilloscope screen, and placed his/her head in a headrest which positioned his/her eyes about 47.6 cm away from the center of the oscilloscope screen. The subject responded using two centrally located 5.08 x 1.9 cm microswitch keys mounted on a keyboard sitting on the table. A Bogen D-22 intercom was used for communication between subject and experimenter.

Stimuli. The stimuli consisted of pairs of upper case letters selected from the set M, T, X, H. These letters were selected because they are bi-laterally symmetrical, and therefore more likely to be matched to one another in a holistic fashion. Each letter measured .64 x 1.0 cm and subtended .8 degrees of horizontal visual angle.

Each stimulus pair was vertically arranged with a separation of 1.3 cm between the bottom of the upper letter and the top of the lower letter.

A trial block consisted of 60 pairs of letters, 30 pairs consisting of physically matching letters (match pairs). Within each subset of 30 match pairs and 30 mismatch pairs, 10 pairs appeared in the left visual field, 10 in the right visual field and 10 in the center of the field, relative to a central fixation point. Pairs in the left or right visual field were located between 3.1 and 3.8 degrees to the left or right of the fixation point. Centrally located pairs had one letter directly above the fixation point, and one letter directly below the fixation point. All pairs were centered around the horizontal axis of the fixation point.

Within the above restrictions, the order in which the different types of pairs appeared within a trial block, as well as the letters making up the specific types of pairs, were randomly determined by a Hewlett Packard 2114B computer. The computer generated stimulus tapes, each dictating 6 blocks of stimuli. Each subject was tested using two different tapes, randomly assigned to them.

Procedure. Subjects were tested individually on two successive days during sessions lasting approximately one hour each. At the beginning of each session, subjects were informed of the response assignment for that session. Half the subjects used their right hand on Day 1 and their left hand on Day 2; the other subjects followed the reverse procedure. Subjects were told to use only the response keys under their middle and index fingers.

Each session consisted of 6 blocks of 60 trials. The first block of each session was a practice block. Each block began with the appearance of the word "READY" in the center of the screen. When the subject was ready, s/he pressed both response keys to begin the trial block. Each trial proceeded as follows. A small fixation plus appeared in the center of the screen. The subject was instructed to carefully fixate on the plus, and when fixated, to press both response keys. The fixation point remained on, but 500 msec later a stimulus pair appeared for 150 msec in the left, right or center of the visual field. The stimulus pair was followed by a 125 msec mask, formed by simultaneously plotting 4 letters, not in the stimulus set, over each member of the stimulus pair. The fixation plus disappeared with the offset of the stimulus pair. The subject's task was to judge whether the stimulus pair was a match or a mismatch, and to indicate a match by a keypress of their index finger, and a mismatch by a keypress of their middle finger. Following the response, performance feedback appeared for 1 sec in the center of the screen below the former location of the fixation point. If the subject had responded correctly, the reaction time in msec appeared. If the response had been incorrect, the word "ERROR" appeared. Following this feedback, the plus reappeared signalling the beginning of a new trial.

Subjects were encouraged to try to regard the letters as shapes, and to avoid naming them. The importance of fixating centrally at all times, except when looking at performance feedback, was emphasized. Subjects were told to respond quickly, but to try to make fewer than 6 errors per block. At the end of each block, they were given feedback on their reaction times and error rate for that block, and were encouraged to slow down or speed up, depending on their error rate.

Following the second session, most subjects reported that they had not named the letters in making their judgments, and that they had been able to fixate centrally on most trials.

Results

For each subject, data from the five test blocks for each session was collapsed to obtain a median reaction time for each stimulus type by visual field by responding hand condition. The medians were subject to a three way within-subjects analysis of variance, using responding hand, visual field, and type of stimulus pair as factors. The means of the medians are displayed in Table 1. The main effects of stimulus type and visual field were significant. The mean reaction time for match pairs was 503 msec, which was 40 msec faster than the mean reaction time to mismatch pairs ($F(1,16) = 18.56$, $p < .001$). The main effect of visual field ($F(2,32) = 6.05$, $p < .05$) was subject to further tests which indicated that reaction times to pairs in the left visual field were 10 msec faster than those to pairs in the right visual field

Table 1. Experiment 1: Mean reaction times (in msec)

		Visual Field			Left-Right Visual Field
Responding Hand	Stimulus Type	Left	Right	Center	
Left	Match	527	520	497	+ 7
	Mismatch	550	533	548	+ 17
Right	Match	477	527	473	- 50
	Mismatch	535	549	548	- 14

($t(1,16) = 2.17$, $p < .05$).[1]

In addition to the above mentioned main effects, the responding hand by visual field interaction was highly significant ($F(2,32) = 16.54$, $p < .001$), and is displayed in Figure 2. Further tests indicated that for the right hand, responses to the left visual field stimuli were 32 msec faster than those to right visual field stimuli ($t(1,16) = 4.58$, $p < .05$). For left hand responses, the difference between the left and right visual fields was not significant, though it tended to be in the opposite direction from that seen for the right hand response. Using the Tukey procedure, a post hoc comparison indicated that there was a significant difference between the right and left hand responses to stimuli presented in the left visual field ($q(2.16) = 2.63$, $p < .10$).[2]

The stimulus type by visual field interaction was also significant ($F(2.32) = 12.75$, $p < .005$). When data from the center visual field was excluded, this interaction was no longer significant.

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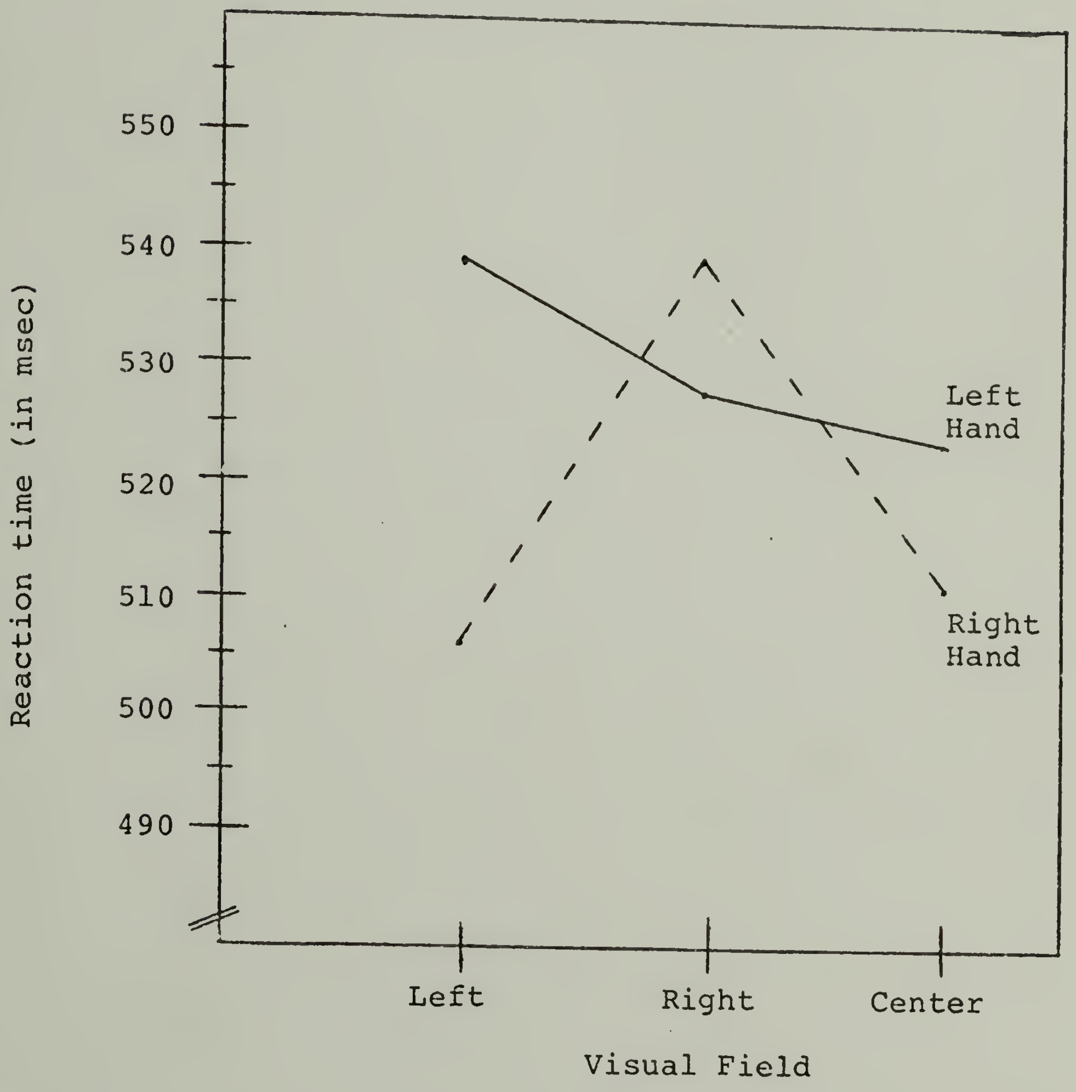
[1] In analyzing this experiment and the others, examination of effects associated with the visual field factor focuses on differences between the right and left visual fields, which are most important for the present purposes. When several planned contrasts were done, the Bonferroni approach for controlling the Type I error rate was used. The error rate reported is the total error rate allowed for the entire set of contrasts done in a given experiment.

[2] Meyers (1972) suggests that the experiment-wise error rate be adjusted to .10 to reduce the power problem when doing post hoc comparisons.

Figure 2. Experiment 1: Reaction times (in msec) as a function of responding hand and visual field



The percentage of errors for each condition is indicated in Table 2. A three way within-subjects analysis of variance was performed on an arc sin transformation of the percentage of errors. The significant effects are listed in Appendix A. Of particular interest is the pattern indicating that for right hand responses, fewer errors were made in the left visual field, while for left hand responses, the opposite is true. There is no evidence of a speed-accuracy tradeoff.

Discussion

Experiment 1 was designed to examine the nature of interactions between stimulus and response processing demands, noting, in particular, whether an interference interaction occurred. The two most important results are the following. First, the results replicate studies reporting a right hemisphere advantage for the physical identity letter matching task, and thus establish the validity of the methodology employed. Second, and more important for the present purposes, is the clear evidence for interaction between stimulus and response processing demands. The nature of this interaction is consistent with the third possible outcome described in the introduction to this experiment. That is, the right hemisphere is significantly faster, and more accurate than the left hemisphere when the right hand responds, but not when the left hand responds.

Table 2. Experiment 1: Percentage of errors

		Visual Field		
Responding Hand	Stimulus Type	Left	Right	Center
Left	Match	10	10	4
	Mismatch	10	8	10
Right	Match	6	14	4
	Mismatch	11	9	11

The nature of this interaction is interesting in several respects. First, it can be described as an interference interaction--performance is less efficient when the stimulus is projected to the hemisphere controlling the response. Secondly, there appear to be differences between the hemispheres in the effect of having to control the response. When the left hemisphere has received the stimulus, performance tends to be better when the right hemisphere controls the response. However, the interference interaction is considerably more striking in cases when the stimulus is received by the right hemisphere, which is supposedly specialized for stimulus processing. In this case, there is a 32 msec difference in response times between conditions in which that hemisphere also controls the response, compared to when it does not.

The presence of the interference interaction also clearly demonstrates that reaction time studies of hemispheric activity must pay more attention to response factors. Response factors may be mediating reaction time differences between visual fields that have, in the past, been interpreted solely in terms of ideas about hemispheric specialization. The fact that use of the left hand response not only reduced the left visual field advantage, but also was associated with a tendency toward a right visual field advantage suggests that interaction effects can be of significant size, and can easily confound reaction time studies which do not control such effects. If, in the present experiment, only a left hand response had been used, the lack of a difference between visual fields might have mistakenly led one to conclude either, that the physical identity matching task was not performed through use of visuo-spatial codes, or that the right hemisphere was not specialized for visuo-spatial processing. These conclusions are invalidated when use of the left hand response is counter-balanced by use of the right hand response.

CHAPTER V

EXPERIMENT 2

Introduction

The results of Experiment 1 clearly establish the presence of an interaction between stimulus and response processing demands, which can be described as an interference interaction. Experiment 2 was an initial attempt to examine whether this phenomenon generalized beyond the conditions of Experiment 1. In Experiment 2, the stimulus processing task was identical to that required in Experiment 1, but response requirements were different. Subjects were required to perform a physical identity letter matching task, but used a bimanual choice response, in which one response was assigned to one finger on one hand, and the other response was assigned to the corresponding finger on the other hand. The response assignment was counterbalanced between subjects.

The results of Experiment 2 are especially useful for assessing how important it was to the results of Experiment 1 to have had only one hemisphere controlling both responses used within an experimental session. It could be argued that, relative to a simple reaction time response, or a bimanual choice response, a unimanual choice response is relatively more difficult, and thus liable to more fully occupy the processing capacity of the single hemisphere controlling it. It is possible that this relatively demanding condition is necessary for the occurrence of the interference seen when stimuli are projected to the hemisphere controlling the unimanual choice response. However, when both hemispheres are associated with the response processes, as is the case with the bimanual choice response, the processing capacities of the hemispheres may be more equally taxed, or less taxed, by the response. In this case, interference may be more equally experienced by the hemispheres, or reduced overall, and thus may have a less visible effect on performance. The weakening or disappearance of the visual field by responding hand interaction would suggest that consistent control of response processes within a single hemisphere is critical for interference to be observed.

Method

Subjects. Twenty University of Massachusetts undergraduates, 10 males and 10 females, were tested. They came from the population described in Experiment 1.

Apparatus. The apparatus described in Experiment 1 was used.

Stimuli. The stimuli and stimulus tapes described in Experiment 1 were used. Each subject was exposed to one randomly assigned tape.

Procedure. The procedure was identical to that used in Experiment 1, with the following exceptions. Subjects were tested during only one session lasting approximately one hour. They were exposed to six blocks of sixty trials, the first block being a practice block. Subjects used a bimanual choice response, in which the index fingers of their left and right hands were used to indicate a match or a mismatch response. Half of the subjects used their right index finger for a match, and their left finger for a mismatch. The response assignment was reversed for the other half of the subjects.

Results

For each subject, the median reaction time for the five test blocks for each stimulus type by responding hand by visual field combination was calculated. An analysis of variance of these medians was performed, with one between-subjects factor (response assignment) and two within-subjects factors (stimulus type, visual field).[3] The means of the medians are displayed in Table 3. The only significant effect was that of stimulus type; matches were faster than mismatches ($F(1,18) = 5.01$, $p < .05$). Although the main effect of visual field was not significant, further tests

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[3] In Experiments 2, 3 and 4, equal numbers of male and female subjects were tested. No evidence for sex differences was revealed by informal surveys of the data.

Table 3. Experiment 2: Mean reaction times (in msec)

Responding Hand	Stimulus Type	Left	Right	Center	Left-Right Visual Field
Left	Match	520	516	476	+ 4
	Mismatch	555	551	554	+ 4
Right	Match	518	533	500	- 15
	Mismatch	511	548	543	- 37

indicated that when the right hand responded, there was a significant difference between the left and right visual fields (t(1,19) = 2.44, $p < .05$). For the left hand, this difference was not significant. Figure 3 displays the performance for the left and right hands.

The error data is displayed in Table 4. An analysis of variance was done on an arc sin transformation of the percentage of errors. The significant effects are listed in Appendix B. There was no evidence of speed-accuracy tradeoffs which would account for the reaction time patterns.

Discussion

Experiment 2 was designed to examine the generalizability of the stimulus-response processing interaction observed in Experiment 1. The results do clearly provide evidence of an interference interaction. Although there is no significant overall difference between responses elicited by right and left visual field stimuli, a significant difference favoring left visual field stimuli does occur when the right hand is responding. This pattern suggests that the right hemisphere was more efficient than the left hemisphere only when the right hemisphere did not have to elicit the response. This pattern is very similar to that observed in Experiment 1. The results are also consistent with those of Experiment 1 in that having to control the response tended to have a greater effect on right hemisphere performance than

Figure 3. Experiment 2: Reaction times (in msec) as a function of responding hand and visual field

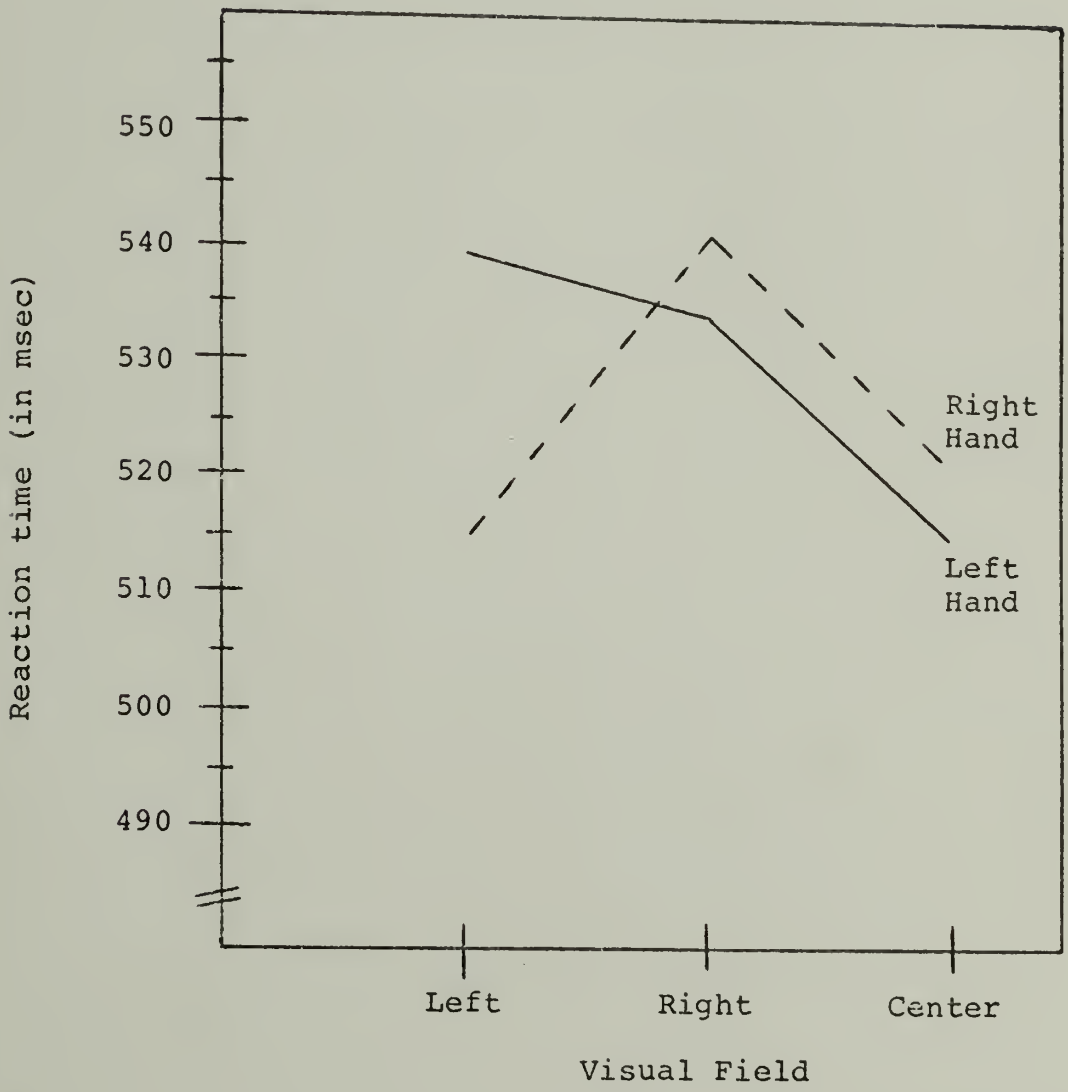


Table 4. Experiment 2: Percentage of errors

		Visual Field		
Responding Hand	Stimulus Type	Left	Right	Center
Left	Match	10.6	10.6	4.0
	Mismatch	8.8	8.0	10.0
Right	Match	11.4	12.4	4.5
	Mismatch	6.2	8.2	11.0

on left hemisphere performance.

The results of Experiment 2 have several other interesting implications. First, they indicate that consistent response control within a single hemisphere is not necessary for there to be an interference interaction. The fact that the interaction appears in conditions where the responding hemisphere is constantly varying suggests that the factors responsible for the interaction must be sensitive to very rapid and fluctuating processing demands.

Second, the fact that the interference interaction appears with use of a bimanual choice response confirms the notion that either there is contralateral control of each hand, or at least, that contralateral control is preferred over ipsilateral control. If the finger movements of each hand were bilaterally controlled, there should be no interference between stimulus and response processing demands, since the hemisphere not receiving the stimulus could control the response. The presence of the interaction with use of a bimanual choice response suggests that this type of response cannot be classified with gross hand movements thought to be under bilateral control (Myers, 1962).

Third, the results have some strong methodological implications for studies of right hemisphere specialization. Both Experiments 1 and 2 suggest that use of only a right hand response facilitates the appearance of differences between the hemispheres. The lack of a significant difference between the right and left visual fields in Experiment 2 suggests that evidence for right hemisphere specialization may appear less clearly when a bimanual response is used. The involvement of both hemispheres in response processes may increase the variability of performance, thus preventing the clear emergence of differences due to specialization. The present results also suggest that use of only a right hand response may produce a tendency toward a left visual field advantage which is not a function of hemispheric specialization, but which merely reflects the fact that processing is more efficient when one hemisphere receives the stimulus and the other controls the response.

CHAPTER VI

EXPERIMENT 3

Introduction

Experiment 1 suggested that in a physical identity letter matching task, there was an interference interaction between stimulus and response processing demands. Experiment 2 indicated that this effect was also present in conditions where response processing demands fluctuated randomly between the two hemispheres. Experiment 3 further tested the generalizability of the interference interaction by maintaining the unimanual choice response used in Experiment 1, but changing the stimulus processing demands. In Experiment 3, subjects were required to perform a verbal matching task similar to that used by Gross (1972). Subjects were required to judge whether two three-letter words matched one another in concept. When a manual response was used, Gross found a 26 to 42 msec right visual field advantage for both match and mismatch responses, supposedly reflecting left hemisphere specialization for the verbal task.

Use of Gross' verbal task with a unimanual choice response seemed worthwhile in several respects. First, the results would suggest whether the interference observed in

Experiments 1 and 2 generalized to conditions where processing requirements were dissimilar to those of the physical identity matching task. If the interference did generalize, then the visual field by response interaction should still be present in Experiment 3, but in exactly the opposite direction. There should be an overall left hemisphere advantage for the verbal task, with this effect appearing more strongly when the left hand was used.

Secondly, the results are particularly important for eliminating the possibility that in Experiments 1 and 2, a lack of left hand coordination was responsible for the failure of a visual field difference to appear when the left hand responded. The presence of interactions, in the opposite directions, in Experiments 1 and 2, and in Experiment 3, may help eliminate this possibility.

Third, the presence of the visual field by response interaction in Experiment 3 would increase understanding of the importance of response control largely within a hemisphere, as is the case with the unimanual choice response. Gross (1972) used the verbal task of Experiment 3, but required subjects to indicate their judgment by using the thumb and forefinger of their responding hand to push a lever up or down. Her results show a nonsignificant tendency for there to be a smaller left hemisphere advantage when subjects used their right hand to perform the task. This pattern of results suggests an interference effect similar to that observed in Experiment 1, though for a left hemisphere task. It is possible that the effect failed to achieve significance in the Gross study because response processes were not well confined to one hemisphere. Though the response lever was held between two fingers, the up-down movement of a lever seems to involve a whole hand movement, which may be bilaterally controlled (Myers, 1962). If the pattern of results seen in the Gross study achieves significance in Experiment 3, this would suggest that, in a verbal task at least, control of response processes by a single hemisphere is a critical factor for obtaining interference.

Method

Subjects. Twenty University of Massachusetts undergraduates were tested. They were from the same population as that used in Experiments 1 and 2.

Apparatus. The apparatus used in Experiments 1 and 2 was used.

Stimuli. The stimuli consisted of pairs of three letter words from the stimulus set used by Gross (1972). The words were eight animal words (ape, cat, cow, dog, elk, hen, pig, rat), and eight body part words (arm, ear, eye, hip, jaw, leg, rib, toe). Since it is believed that three letter words are usually perceived as units (Krueger, 1970), their use might be expected to minimize left-to-right scanning that could confound the results. The words in a pair were vertically arranged, one above the other, with a vertical separation of 1/2 inch.

A trial block consisted of 60 pairs of words, 15 pairs containing both animal words, 15 pairs containing both body part words, and 30 pairs differing in word type. Within each of these subsets, 1/3 appeared in the left visual field, 1/3 appeared in the right visual field, and 1/3 appeared in the center. Pairs in the left or right visual field were located between 3 to 5 degrees to the left or right of the central fixation point. Central pairs had one word directly above the fixation point and one word directly below the fixation point. All pairs were centered around the horizontal axis of the fixation point.

Within the above constraints, the order in which the different types of pairs appeared within a trial block, as well as the letters making up the specific types of pairs, were randomly determined by an HP 2114B computer. The computer generated stimulus tapes, each dictating five blocks of stimuli. Each subject was tested with randomly assigned tapes.

Procedure. The procedure was identical to that used in Experiment 1, with the following exceptions. Rather than judging the physical identity of the stimuli matches, subjects were required to judge whether the pairs of words matched or mismatched in conceptual category. Before actual testing, subjects were required to memorize the words in each class, to familiarize them with the possible stimuli and their appropriate conceptual categories. Half the subjects used their left hand during the first session, and their right hand during the second session. The other subjects followed the reverse response order. During each session, each subject received one practice block and four test blocks.

Results

The test blocks were collapsed for each subject for each session to obtain the median reaction time for each stimulus type by responding hand by visual field by response order condition. The means of these medians were subject to an analysis of variance, with one between subjects variable (response order), and three within subjects variables (stimulus type, responding hand, and visual field). Table 5 displays the means, combining hand order, which had no significant effect. Match responses were 121 msec faster than mismatch responses ($F(1,18) = 71.23$, $p < .001$). The field main effect was significant ($F(2,36) = 54.75$, $p < .001$). Further tests indicated that the right visual field was 60 msec faster than the left visual field ($t(1,19) = 3.8$, $p < .01$). The difference between the left and right visual fields did not vary as a function of responding hand.

The hand order by responding hand interaction was significant ($F(1,18) = 107.93$, $p < .001$), as was the stimu-

Table 5. Experiment 3: Mean reaction times (in msec)

		Visual Field			Left-Right Visual Field
Responding Hand	Stimulus Type	Left	Right	Center	
Left	Match	1087	1039	917	+ 48
	Mismatch	1216	1153	1043	+ 63
Right	Match	1094	1017	931	+ 77
	Mismatch	1218	1165	1018	+ 53

lus type by response order by responding hand interaction ($F(1,18) = 5.3$, $p < .05$). As shown in Figure 4, if the right hand was used during the first session, the left hand responses were faster than the right hand responses. The opposite was true if the left hand was used during the first session. This effect was more pronounced for mismatch responses than for match responses.

The error data is displayed in Table 6. An analysis of variance was done on an arc sin transformation of the percentage of errors. The significant effects are listed in Appendix C. There was no evidence of a speed-accuracy tradeoff with reference to the reaction time patterns described above.

Discussion

Experiment 3 attempted to examine whether there was intra-hemispheric interference between stimulus and response processing demands in a task having the same response requirements as Experiment 1, but requiring stimulus processing for which the left hemisphere was specialized. The results of Experiment 3 show a consistent and relatively large right visual field advantage, which does not vary with the response requirements. These results suggest that there was no interference between stimulus and response processing requirements in the conditions of Experiment 3.

This outcome is rather unexpected, especially since

Figure 4. Experiment 3: Interaction between stimulus type, responding hand, response assignment

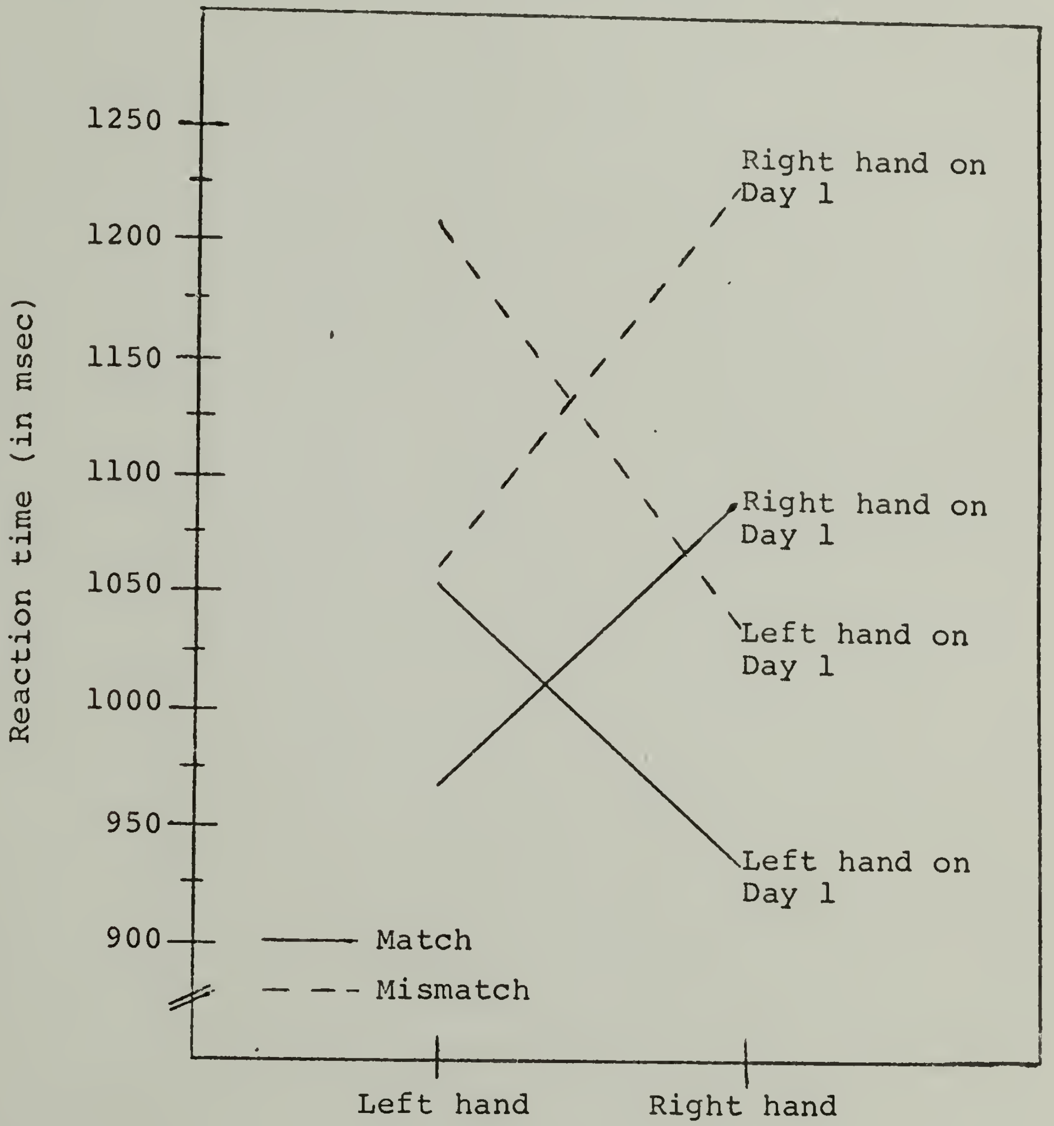


Table 6. Experiment 3: Percentage of errors.

		Visual Field		
Responding Hand	Stimulus Type	Left	Right	Center
Left	Match	9.8	8.3	2.5
	Mismatch	12.5	12.4	4.9
Right	Match	7.9	6.9	2.8
	Mismatch	11.4	10.4	6.0

Gross (1972), using the same task, observed nonsignificant trends in her data that were consistent with the existence of an interference interaction. There are, however, some differences between the two experiments that may help to explain the differences in outcomes. First of all, the error rate in Gross's experiment averaged around 4.5 per cent; the error rate in Experiment 3 for the left and right visual field stimuli was closer to 10.0 per cent. Many subjects in Experiment 3 also spontaneously reported great difficulty in recognizing the stimulus words, which were plotted on an oscilloscope display. Consequent variability and instability of performance may have either minimized the overall importance of stimulus-response processing interference in determining reaction times, or at least, have masked the presence of such effects.

A second possible explanation of the data arises from Kinsbourne's notion that activation of a hemisphere may bias attention toward the contralateral visual field. In Experiment 3, constant reception of verbal stimuli and consequent activation of the left hemisphere could have biased attention toward the right visual field, thereby enhancing the size of the right visual field advantage already associated with left hemisphere specialization for the verbal task. Such biases may be especially powerful as a function of verbal hemisphere activation, since that hemisphere predominates in so much of human activity. Such biases may be less influential where subjects have less practice doing a consistent type of stimulus processing, as may be the case in studies by Gross (1972) and Geffen, Bradshaw, and Nettleton (1972). In addition, the horizontal arrangement of the letters of each word may have further encouraged left-to-right attentional scanning, as in reading, which also increased the right visual field advantage.

In summary, it is possible that in Experiment 3, the effects of at least two factors, performance instability, and attentional biases, may have masked the appearance of interference effects. Although the results are therefore inconclusive with respect to establishing the generalizability of the interference interaction, they do point out once again the variety of factors that can influence reaction time studies of hemispheric activity.

CHAPTER VII

EXPERIMENT 4

Introduction

The previous discussion suggests that the interaction between stimulus and response processing may be masked in conditions where performance is unstable, and when attentional biases are likely. The major purpose of Experiment 4 was to further examine the importance of the interference interaction for verbal task performance, in conditions better designed to increase its visibility.

In Experiment 4, subjects were required to use a unimanual choice response to indicate whether two letters, differing in case, matched one another in name. A "name identity" matching task such as this generally takes 70 to 100 msec longer than the physical identity matching tasks used in Experiments 1 and 2, and is believed to involve recognition and matching of the verbal codes for the two letters (Posner, Boies, Eichelman, and Taylor, 1969). Several studies (Cohen, 1972; Geffen, Bradshaw, and Nettleton, 1972) have observed a right visual field advantage for the name identity matching task, supporting the notion that the task involves verbal processing by the left hemisphere.

This particular verbal task was selected for several reasons. First, the task is a simpler task than the concept matching task of Experiment 3, and was likely to be performed more quickly, more accurately, and more stably. To perform the name matching task, subjects need only perceive two letters, and recognize their name. Difficulties associated with subjects' inability to recognize the words presented on the oscilloscope display were therefore reduced.

Secondly, with the name matching task, the stimulus letters could be vertically arranged, one above the other. In Experiment 3, there is the possibility that left-to-right attentional scanning was promoted by the horizontal presentation of the words, thus increasing performance variability, and possibly making the interference interaction.

In addition to performing the name matching task, subjects were required, during each session of Experiment 4, to also perform the physical identity letter matching task used in Experiments 1 and 2. Inclusion of this task allowed better control of attentional biases, as well as a replication of Experiment 1.

Method

Subjects. Twenty University of Massachusetts undergraduates were tested. They came from the population described in Experiment 1.

Apparatus. The apparatus described in Experiment 1 was used.

Stimuli. The stimuli consisted of pairs of letters selected from the set R,D,H,L. These letters were selected because they were judged by the experimenter to be most easily recognizable, and minimally confisable both auditorily and visually, when plotted on the oscilloscope display. Each letter measures .64 x 1.0 cm and subtended .8 degrees of visual angle.

Each stimulus pair was vertically arranged with a separation of 1.3 cm between the bottom of the upper letter and the top of the lower letter.

A trial block consisted of 60 pairs of letters--30 "match" pairs and 30 "mismatch" pairs. For the physical identity letter matching task, only upper case letters were used. A match pair consisted of two physically identical upper case letters, and a mismatch consisted of two physically dissimilar upper case letters. For the name identity matching task, each pair consisted of one upper and one lower case letter, each randomly assigned to the top or bottom position of the pair. A match pair consisted of two letters which agreed in name (i.e., $\begin{matrix}A\\a\end{matrix}$) and a mismatch pair consisted of two letters differing in name (i.e., $\begin{matrix}A\\b\end{matrix}$).

Regardless of task, within each subset of 30 match pairs and 30 mismatch pairs, 10 pairs appeared in the left visual field, 10 in the right visual field, and 10 in the center of the field, relative to a central fixation point.

Pairs in the left or right visual field were located between 3.1 and 3.8 degrees to the left or right of the fixation point. Centrally located pairs had one letter directly above the fixation point, and one letter directly below the fixation point. All pairs were centered around the horizontal axis of the fixation point.

Within the above restrictions, the order in which the different types of pairs appeared within a trial block, as well as the letters making up the specific types of pairs, were randomly determined by an HP 2114B computer. The computer generated stimulus tapes, each dictating four blocks of stimuli, which were randomly assigned to subjects.

Procedure. Subjects were tested individually on two successive days during sessions lasting approximately one and one-half hours each. Each session consisted of eight blocks of trials--four blocks on the physical identity matching task, and four blocks on the name matching task. Half of the subjects did the physical identity task before the name matching task, and half had the reverse order. Within each of these groups, half of the subjects used their right hand during the first session, and their left hand during the second session, and half followed the reverse procedure. Subjects used the response keys under their middle and index fingers.

At the beginning of the first session, the subject was given instructions relevant to the first task s/he was to perform, and was informed of the response assignment for that session. The subject was then exposed to one practice block on that task, followed by three test blocks. The sequence of events within each block was identical to that described for blocks in Experiment 1. After completing the first task, subjects were given a short rest, and were then given instructions relevant to the second task. They had one practice block on the second task, and then three test blocks.

When performing the physical identity matching task, subjects were encouraged to try to regard the letters as shapes, and to avoid naming them. When performing the name matching task, it was pointed out that physical identity provided inaccurate information, and that letter names were the most reliable cues. The importance of fixating centrally at all times, except when looking at performance feedback, was emphasized. Subjects were told to respond quickly, but to try to make fewer than six errors per block. At the end of each block, they were given feedback on their reaction times and error rate for that block, and were encouraged to slow down or speed up, depending on their error rate.

Following the second session, most subjects reported that they had been able to fixate centrally on most trials, and had been unaware of eye movements that may have occurred.

Results

For each subject, the median for reaction times in the test blocks for each combination of conditions was calculated. An analysis of variance on these medians was performed, with response order and task order as between-subjects variables, and task, stimulus type, visual field, and responding hand as within-subjects variables. Significant main and interaction effects are listed in Table 7. In view of the purpose of the research, and to simplify consideration of the data, the review below will focus on significant main effects and highly significant interactions involving either the field variable, or the response by field interaction. Other significant first order interactions are displayed in Appendix D. It is believed that the significant effects not reviewed below would not change the basic interpretation of the results.

Table 8 indicates the means for each combination of task, stimulus type, visual field, and responding hand. Responses to the physical identity matching task were 208 msec faster than those to the name matching task ($F(1,16) = 100.0$, $p < .001$). Match responses were 50 msec faster than mismatch responses ($F(1, 16) = 30.0$, $p < .001$). The field main effect was significant ($F(2,32) = 13.7$, $p < .005$). Further tests indicated that right visual field responses tended to be faster than left visual field responses ($t(1,19) = 2.30$, $.10 < p < .05$).

Table 7. Experiment 4: Significant effects in the analysis of variance of reaction times, combining both tasks.

Effect	Significance Level
T	$p < .001$
K	$p < .001$
F	$p < .005$
XT	$p < .001$
YR	$p < .001$
XF	$p < .05$
TF	$p < .05$
RF	$p < .005$
YRT	$p < .001$
XTK	$p < .05$
XTF	$p < .01$
YTF	$p < .05$
XKF	$p < .05$
XYRT	$p < .001$
RTKF	$p < .001$
XYRFK	$p < .05$

X = task order

Y = response assignment

T = task

R = responding hand

K = stimulus type

F = visual field

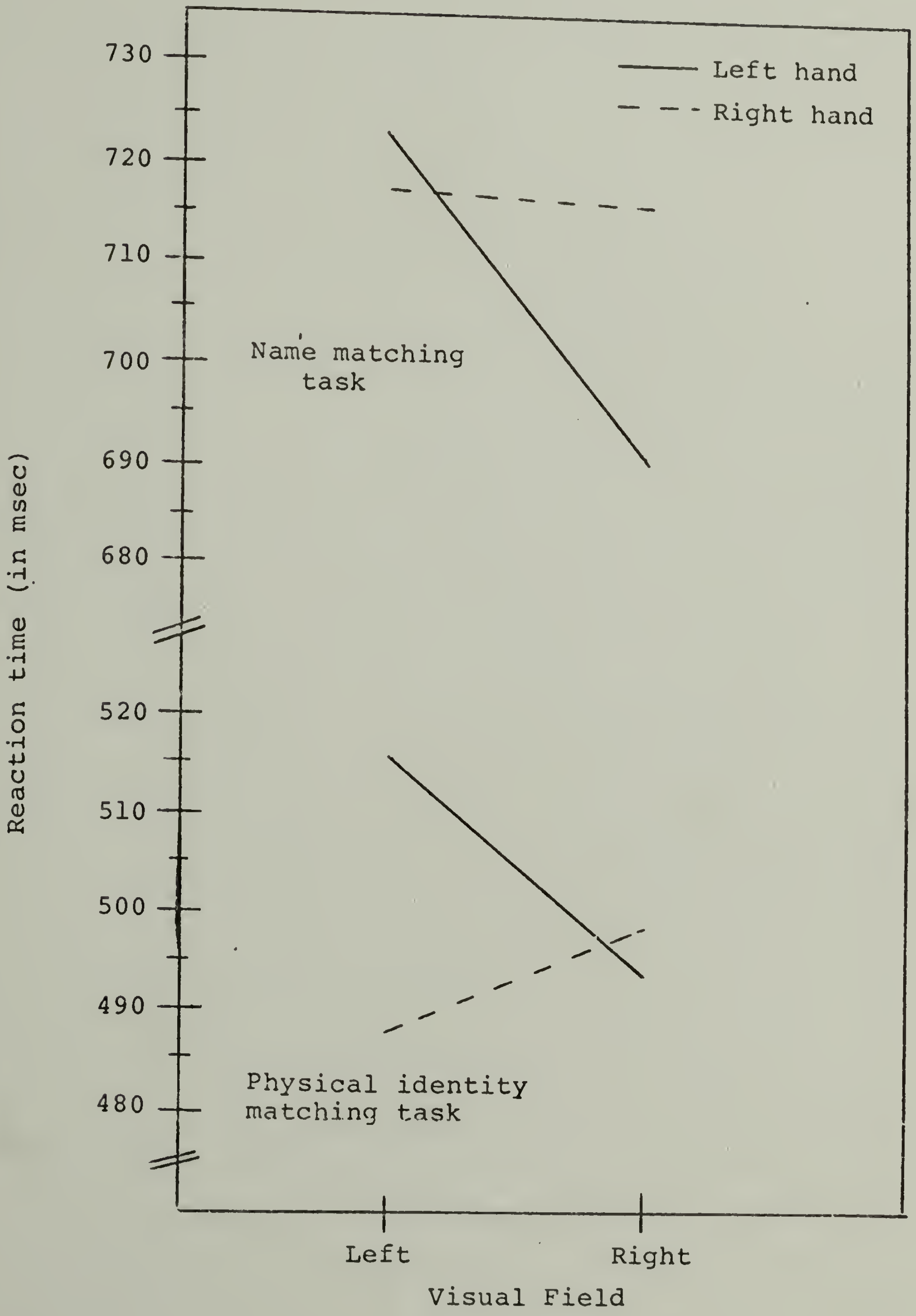
Table 8. Experiment 4: Mean reaction times (in msec)

		Responding Hand	Stimulus Type	Visual Field			Left-Right Visual Field
				Left	Right	Center	
TASK	Physical Identity Matching	Left	Match	500	465	469	+ 35
			Mismatch	531	523	520	+ 8
		Right	Match	457	475	447	- 18
			Mismatch	520	520	512	- 10
	Name Matching	Left	Match	693	673	660	+ 20
			Mismatch	752	707	714	+ 45
		Right	Match	702	679	667	+ 23
			Mismatch	732	753	708	- 21

The visual field by responding hand interaction was significant ($F(2,32) = 7.2$, $p < .005$). Further tests indicated that when the left hand responded, the right visual field was 27 msec faster than the left visual field ($t(1,19) = 5.76$, $p < .05$). When the right hand responded, the difference between the left and right visual fields was not significant, but tended to favor the right visual field. Further tests of the significant visual field by task order interaction ($F(2,36) = 4.11$, $p < .05$) indicated that the right visual field advantage occurred only when the name matching task preceded the physical identity matching task ($t(1,19) = 3.23$, $p < .01$). When the center visual field was excluded, the task by visual field interaction was significant only at the .10 level, but suggests that the right visual field advantage was larger for the name matching task.

An analysis of variance was also done for each task separately, using task order and hand order as between-subjects variables, and stimulus type, visual field, and responding hand as within-subjects variables. Since primary interest is in differences between the left and right visual fields, data from the center visual field was excluded in this analysis. For each task, the responding hand by visual field interaction was significant (for the physical identity task: $F(1,16) = 12.16$, $p < .005$; for the name matching task: $F(1,16) = 5.63$, $p < .05$). Figure 5 displays these interactions. Further tests indicated that for the physical matching

Figure 5. Visual field by responding hand interactions for each task



task, the 13 msec left visual field advantage when the right hand responded tended to be significant ($t(1,19) = 2.22$, $.10 > p > .05$). The 21 msec right visual field advantage when the left hand responded also tended to be significant ($t(1,19) = 2.39$, $.10 > p > .05$). Further tests of the name matching task indicated that there was a significant 32 msec right visual field advantage when the left hand responded ($t(1,19) = 3.68$, $p < .05$). When the right hand responded, although the overall means favor the right visual field, this tendency was not significant. Examination of the data for right hand responses suggested that although several subjects did show a large right visual field advantage, this effect was not at all consistent across subjects. Appendix E lists other significant, but less interesting, effects for each task.

The overall analysis, combining the two tasks, also indicated that the responding hand by visual field by stimulus type by task interaction was significant ($F(2,32) = 5.9$, $p < .001$). This interaction is displayed in Figure 6. For the physical matching task, the responding hand by visual field interaction is more pronounced for matches than for mismatches. For the name matching task, the responding hand by visual field interaction is more pronounced for mismatches than for matches.

The error data is displayed in Table 9. An analysis of variance was performed on an arc sin transformation of the

Figure 6. Experiment 4: Responding hand by visual field by stimulus type interaction

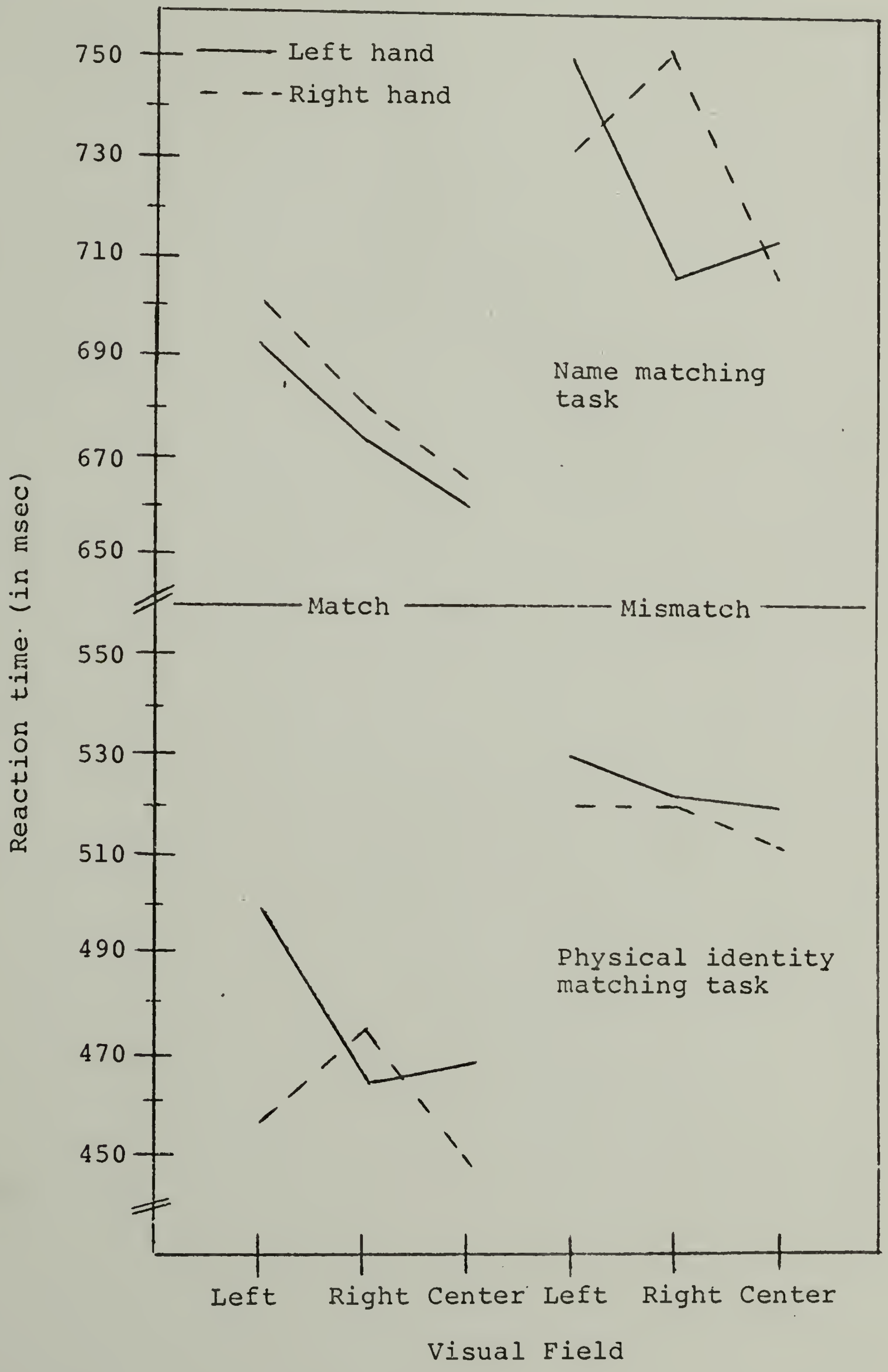


Table 9. Experiment 4: Percentage of errors.

				Visual Field		
		Responding Hand	Stimulus Type	Left	Right	Center
TASK	Physical Identity Matching	Left	Match	8.2	3.5	3.3
			Mismatch	4.0	8.5	3.5
		Right	Match	4.5	6.7	4.7
			Mismatch	7.8	8.0	6.3
	Name Matching	Left	Match	10.0	6.7	8.5
			Mismatch	3.8	5.2	6.2
		Right	Match	12.5	8.0	6.5
			Mismatch	4.7	5.3	7.5

percentage of errors. Significant effects are listed in Appendix F. Further tests were done where trends in the error data tended to contradict the reaction time trends, in terms of goodness of performance. None of these tests were significant.

Discussion

The purpose of Experiment 4 was to examine whether a stimulus-response interaction appeared with a verbal task in conditions where performance was more stable, and where attentional biases might be better controlled than in Experiment 3. The most important findings of Experiment 4 are the following:

(1) For the name matching task, there was an overall right visual field advantage which showed evidence of an interference interaction. When the left hand responded, there was significant 32 msec right visual field advantage, which disappeared when the right hand responded.

(2) For the physical identity matching task, there was no significant difference between the left and right visual fields, but was a significant responding hand by visual field interaction. The difference between visual fields as a function of responding hand tended to reflect the presence of an interference interaction.

(3) For the two tasks combined, there was an overall right visual field advantage, which showed evidence of an interference interaction. When the left hand responded, there was a 27 msec right visual field advantage, which disappeared when the right hand responded.

Most important of all is the first finding--that there was an intra-hemispheric interference interaction between stimulus and response processing demands for the verbal task. The fact that the right visual field advantage associated with hemispheric specialization appeared only with left hand response control confirms the existence of this interaction. As in Experiments 1 and 2, interference as a function of response requirements tended to be greater in the hemisphere specialized for the stimulus processing task. These findings generalize the importance of the interference interaction to performance of a task other than the right hemisphere, physical identity matching task. They demonstrate that this influence is not an artifact of right handed responding by right-handed subjects.

Experiment 4 also succeeded in replicating the presence of an interference interaction in performance of the physical identity matching task. It is interesting to note that performance of this task in Experiment 4 seemed to favor the right visual field more than did performance in Experiment 1. The left visual field advantage for right hand responding was somewhat smaller than that observed in Experiment 1, and there was a significant right visual field advantage when the left hand responded. This pattern suggests that, in Experiment 4, the left hemisphere tended, in some way, to predominate performance, despite the fact that subjects had equal experience with the two types of tasks. This left hemisphere predominance is also suggested by the presence of an overall right visual field advantage, which appeared most strongly in conditions where the name matching task preceded the physical identity matching task.

The nature of the left hemisphere predominance could be of several types. There is, first of all, the possibility that on a certain proportion of the physical identity matching trials, the letter pairs were processed by the left hemisphere in terms of their physical codes. If this were the case, then one would expect physical identity matching reaction times in Experiment 4 to be, in general, somewhat longer than those in Experiments 1 and 2, where verbal processing of physically identical pairs was less likely because there was no verbal task. In fact, responses to the physical identity matching task in Experiment 4 are somewhat faster than those in Experiments 1 and 2.

A second explanation of the left hemisphere predominance is based on the possibility that, despite inclusion of the physical identity matching task, left hemisphere attentional biases might have been imposed on all performance in Experiment 4. Although it was hoped that right and left hemisphere attentional biases would counterbalance one another, left hemisphere activation and associated attentional biases may have more powerful influences than right hemisphere activation. One might argue that this is not unexpected, since most of our information processing is verbally oriented, perhaps making the left hemisphere more able to achieve a higher state of activation. An account which suggests that right hemisphere activation produces relatively less attentional bias would also help explain why, in Experiments 1 and 2, interaction effects appeared even though the right hemisphere was consistently activated by stimulus processing.

The results of Experiment 4 imply several other notable points. First of all, the effects associated with task order suggest that researchers need to carefully consider transfer effects when verbal and spatial tasks are required in one experimental session. Another notable aspect of Experiment 4 is the difference between reaction times to the physical identity and name matching tasks, which was exceptionally large. In particular, responses to the name matching task were longer than is usually reported (Posner, Boies, Eichelman and Taylor, 1969). This observation lends credibility to the suggestion that subjects had difficulty recognizing the letters projected on the oscilloscope display, and that this difficulty may have confounded the results of Experiment 3.

Finally, the presence of the responding hand by visual field by stimulus type by task interaction suggests that the interference interaction may vary somewhat according to task and stimulus type. However, it remains unclear why, in Experiment 4, the interaction appeared most clearly for mismatches in the name matching task, and for matches in the physical identity matching task.

CHAPTER VIII

GENERAL DISCUSSION AND CONCLUSIONS

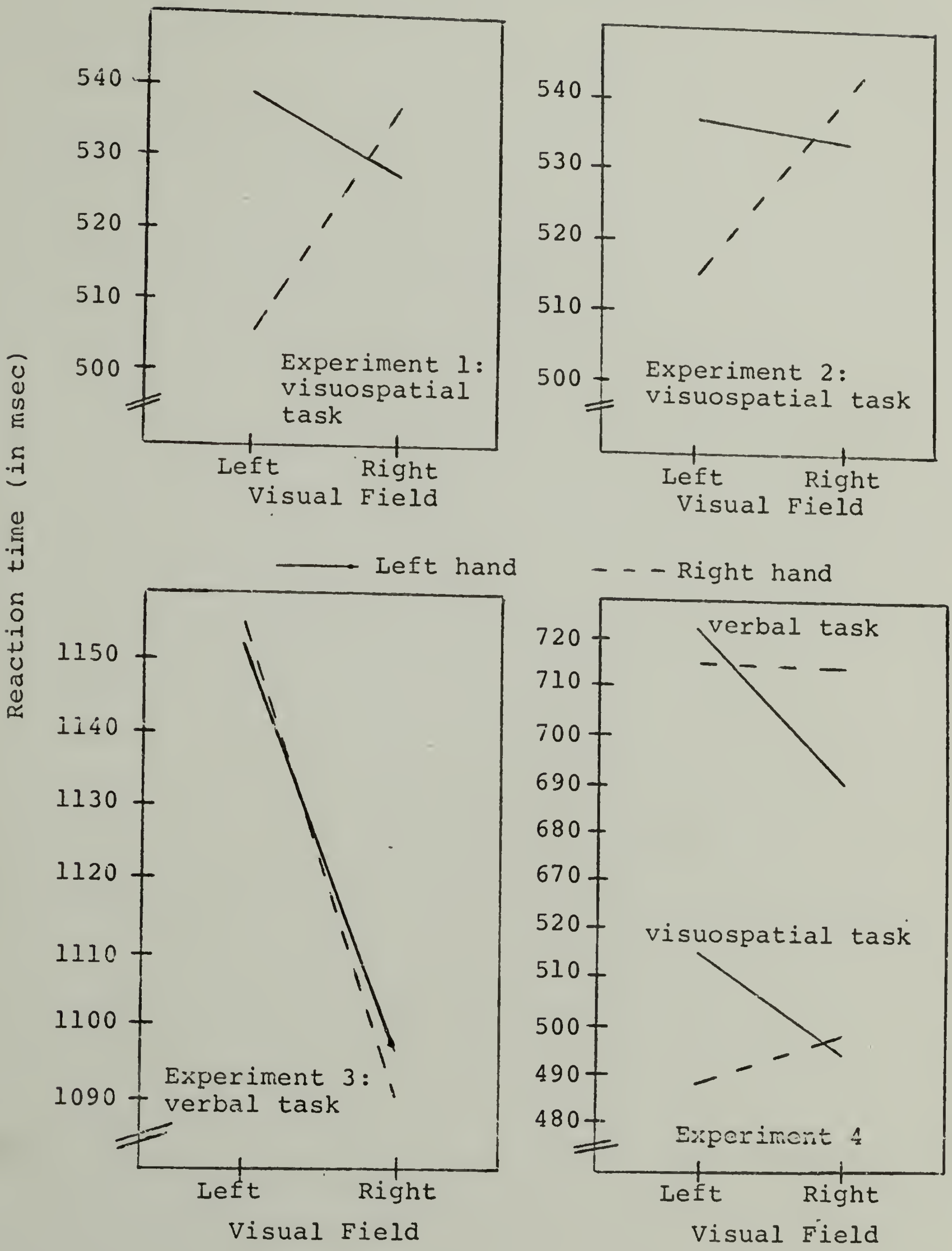
The purpose of the present research was to examine the kind of interaction that occurs between stimulus and response processing demands within a cerebral hemisphere. The review of the relevant literature suggested that at least two types of interactions have been reported--an interference interaction, and a facilitative interaction. For present purposes, an interference interaction was defined as occurring when performance was slower, or less accurate, when the stimulus was projected to the hemisphere controlling the response. A facilitative interaction was said to have occurred when these same conditions yielded better performance. It was pointed out that many studies fail to recognize the possibility of an interference interaction, either assuming the presence of a facilitative interaction, or inadequately controlling for such interactions. Therefore, in the present research, particular interest was focused on the possibility that an interference interaction might occur, and conditions were selected to optimize the likelihood of its appearance, if indeed, it were a reliably appearing phenomenon.

In each of the studies presented here, the responding hand by visual field interaction was examined for presence of facilitation or interference between stimulus and response processing demands. These critical interactions are summarized in Figure 7. With the exception of Experiment 3, there is, in each experiment, clear evidence for an interference interaction between the stimulus and response processing. In Experiments 1, 2 and 4, reaction times are faster, and error rates lower, in conditions where the stimulus is received by the hemisphere which is not involved with response control.

Consideration of all of the experiments together also suggests another interesting phenomenon, which appeared most clearly in Experiment 1. In each experiment where interference occurred, the interference tended to be of greater magnitude within the hemisphere specialized for the task. Where physical identity matching was required, the right hemisphere showed a greater efficiency loss when it had to control the response. Where name matching was required, the left hemisphere showed a greater efficiency loss due to response control.

One possible strategy for understanding these results emerges from consideration of (1) the components of task performance, and (2) possible factors affecting each of these component stages. Components of the present tasks might include the following: (1) reception of stimuli, and development of task-appropriate memory representations (e.g., visuo-

Figure 7. Interference effects for each experiment



spatial representations for the physical identity matching task, name codes for the name matching task), (2) comparison of these representations, (3) judgment of the representations, as matching or not, and (4) translation of the judgment into an appropriate response. One model which is quite useful for describing how each of these components might be limited is provided by Norman and Bobrow (1975). They suggest that performance is a function of "data-limited" processes and "resource-limited" processes. Data-limited processes are affected by the quality of the initial stimulus (e.g., its signal-to-noise ratio), as well as the quality of the stored representation. Resource-limited processes are affected by the availability of a central processing capacity which is shared between a variety of mental operations. According to this model, "when an information processing task is performed, the result depends both upon the quality of the data, and upon the processing resources that are used" (p. 61). More specifically, they suggest that if performance is severely data-limited, the lack of sufficient resources will impose no further disadvantage on performance. However, if performance is not severely data-limited, then the presence or absence of sufficient processing resources will control the quality of performance.

Applying this analysis of performance limits to the previous description of task components, the following explanation of the interference interaction, and its greater effect on the specialized hemisphere, emerges. In the case where the hemisphere specialized for stimulus processing directly received the stimulus, a "good" memory representation could be formed for use during the comparison stage. The comparison and judgment stages, which are data-limited if inappropriate representations are available, were not data-limited in cases where the hemisphere specialized for a task received the stimulus. However, the demand for central processing resources during the temporally proximal judgment and response-making stages may have been greater than the total available processing capacity, thus imposing a resource limit on performance. Thus, although the hemisphere specialized for stimulus processing was not significantly data-limited, resource limits affected performance when that hemisphere had to judge the stimulus as well as organize the response. The improvement in performance seen when the non-specialized hemisphere controlled the response suggests that resource limits were less severe when the non-stimulus-receiving hemisphere controlled the response. This suggests that in the conditions of the present experiments at least, each hemisphere had its own independent processing resources which could not be shared with the other hemisphere.

In cases where the nonspecialized hemisphere received the stimuli, the comparison and judgment stages might have been severely data-limited. If one assumes that the nonspecialized hermisphere does stimulus processing if it receives the stimulus, then data-limits might have been imposed because the non-specialized hemisphere was unable to form memory representations which could be easily used during the comparison and judgment stages. Alternately, one could assume that the nonspecialized hemisphere transfers stimulus information to the specialized hemisphere. Data limits might then have been imposed because the transfer of the initial stimulation across the corpus callosum might have degraded its quality (Cohen, 1972; McKeever and Huling, 1971), thus making it more difficult for even the specialized hemisphere to form a good representation for comparison and judgment. Regardless of how data limits were imposed on these stages, such limits may have been sufficiently severe so that resource limits imposed little or no further detriment on performance. This would explain why response control requirements had less effect on the hemisphere not specialized for the stimulus processing demands of the task.

One of the purposes of the present research was to try to specify some of the conditions in which the interference interaction occurred. The above discussion suggests that interference occurs more strongly in the hemisphere specialized for stimulus processing. Consideration of other literature on stimulus-response processing interactions, as well as some behavioral evidence, provide some other interesting ideas regarding the conditions affecting the presence or absence of interference. For example, interference seems to be absent in conditions involving either simpler stimuli or simpler responses. As has been mentioned, facilitation between stimulus and response processing within a hemisphere has been reported in several studies requiring dot localization or dot detection (Berlucchi et al., 1971; Bradshaw and Perriment, 1970). In addition to using a simple stimulus, Berlucchi et al. also require a simple response, rather than a choice response. Rizzolati, Umilta, and Berlucchi (1971) also found no evidence of an interference interaction in performance of a discrimination task. The required response in their study was a "go-no go" response, in which subjects had to decide whether to respond, but had only one possible response to produce if they decided to respond. These studies suggest that there may be no interference where stimulus and/or response processing demands are relatively simple. In such situations, the processing resources required may not exceed the total available processing resources.

Behavioral evidence suggests that there is also minimal stimulus-processing interference within a hemisphere in a variety of other tasks. Many of these tasks are ones in which response performance can benefit if it is controlled by a hemisphere which is providing input that is useful in modifying that performance. For example, most individuals having a verbal left hemisphere also have a dominant right hand. Thus, most individuals are using the same hemisphere to formulate the content of writing, and to control the manual behavior of writing. In this case, the writing behavior is highly dependent on the input from the left hemisphere, and thus, overall performance may benefit when that hemisphere controls the response. Using a similar line of reasoning, one might also explain why it is that most of the efferent systems involve response control by the hemisphere receiving stimulation. This can be explained when one realizes that most responses that are of high survival value require constant feedback concerning their consequences, so that they can be modified appropriately to insure survival. Because of the organization of the afferent pathways, such feedback is received by the hemisphere contralateral to the space in which the response occurs. Since transfer of information across the corpus callosum may degrade stimuli, or result in longer response times, such feedback may be most useful if response control is within the hemisphere receiving the feedback. It may be that interference occurs mainly in tasks requiring higher mental processes for which one hemisphere is specialized, and where responses are discretely made, and not highly dependent on receiving immediate feedback of their consequences.

The methodological implications of stimulus-response processing interference within a hemisphere have been mentioned before, but need to be briefly summarized here because they are of considerable importance. First, the present results strongly suggest that response requirements must be carefully chosen, and that their effects on patterns of performance must be carefully considered in interpreting data. Although the present discussion has attempted to specify conditions under which different kinds of interactions may occur, this analysis needs further testing before it is used to assess whether interference or facilitation is likely to be occurring in a given experiment. Although such effects were not consistently significant, the present research suggests that practice effects, as well as differences between matches and mismatches, may influence whether interference between stimulus and response processing occurs. Given the present lack of understanding, the most sensible strategy is to counterbalance response assignments as completely as is possible, or at least to examine separately data associated with each response.

A second methodological implication concerns the importance of attentional biases associated with hemispheric activation (Kinsbourne, 1973). Despite the report of Geffen, Bradshaw, and Nettleton (1972), the present research suggests that attentional biases may influence reaction time studies of hemispheric specialization. The most powerful biases may occur when stimulation is received while one hemisphere is concurrently being activated through other task demands, such as has been described in several studies (Kinsbourne, 1973, 1975). Attentional biases may be less influential when they are a function of limited experience with prior stimulus processing demands, or when both hemispheres are continuously activated by involvement in response processes. Kinsbourne's work, as well as the present research, suggests that attentional biases induced by left hemisphere activation may be particularly powerful.

The practical implications of the present research require further exploration, but can be tentatively sketched as follows. In tasks for which one hemisphere is likely to be specialized for stimulus processing, and where responses do not require continuous input from that hemisphere, there may be a performance advantage gained when the hemisphere not occupied with stimulus processing is in control of the response. This appears to be the case in two-choice speeded classification tasks. However, where optimal performance requires continuous cerebral monitoring of the response, there is probably an advantage for one-hemisphere control of both stimulus and response processing.

Further research in this area might be most useful if it focused on identifying the underlying dimension which is responsible for the observed interference. Earlier discussion suggested that the appearance of interference versus facilitation between stimulus and response processing may be a function of overall task difficulty. This notion is supported by the findings of Hellige and Cox (1976), who examined the effects of a concurrent verbal memory task on performance of a visual form recognition task. With no verbal memory task, performance on the visual form recognition task was better for stimuli presented in the left visual field, supposedly due to right hemisphere specialization. With a small verbal memory load, visual recognition was better for stimuli in the right visual field, supposedly due to left hemisphere attentional biases toward the right visual field. However, when the memory load was increased, performance was again better for stimuli presented in the left visual field. Hellige and Cox suggest that, "a relatively difficult concurrent verbal memory load may require so much left hemisphere processing capacity . . . that it interferes with processing of visual stimuli from the right visual field" (p. 214).

These results suggest that by systematically varying the difficulty of stimulus and response processing requirements, one might be able to observe a continuum of effects which included both facilitation and interference at different points. As an extension of the present research, an initial step might involve observing whether interference occurred in a physical identity letter matching task when a very simple response, such as a go-no go response, was required. In increasing the difficulty of the stimulus or response processing, one must beware of choosing task requirements that will produce variability in performance that might mask interesting interactions.

In summary, the present research suggests that interference between stimulus and response processing demands within one hemisphere of the cerebrum does occur under certain conditions. It appears that this interference occurs more strongly within the hemisphere specialized for stimulus processing, possibly as a function of resource limits during the judgment and response organization stages of the task. The present results add further support to the idea that the two hemispheres function to a certain extent as independent processors of information and organizers of behavior. The results suggest that reaction time studies of hemispheric specialization need to carefully control for response biases which might be a function of interference, or facilitation, between stimulus and response processing.

APPENDIX A

Experiment 1: Significant effects in analysis of variance of percentage of errors

Effect	Significance Level
Visual field	$p < .025$
Visual field x responding hand	$p < .05$
Visual field x stimulus type	$p < .01$

APPENDIX B

Experiment 2: Significant effects in analysis of variance of percentage of errors

Effect	Significance Level
Visual field	$p < .01$
Visual field x stimulus type	$p < .001$

APPENDIX C

Experiment 3: Significant effects in analysis of variance of percentage of errors

Effect	Significance Level
Stimulus type	$p < .001$
Visual field	$p < .001$
Responding hand x response assignment . .	$p < .05$

APPENDIX D

Experiment 4: Significant first order interactions (in msec)

Effect

Task order by task

$p < .001$

		Task	
		Physical identity	Name matching
Task Order	PI first	520	640
	NI first	467	766

Response Order by Response

$p < .001$

		Responding Hand	
		Left	Right
Response Order	Left in 1st session	639	543
	Right in 1st session	561	651

Visual field by task order

$p < .05$

		Task order	
		Physical identity matching first	Name matching first
Visual Field	Left	584	635
	Right	585	613
	Center	571	603

Appendix D (Cont.)

<u>Effect</u>

Visual field by task

$p < .05$

		Task	
		Physical identity	Name matching
Visual Field	Left	499	719
	Right	495	703
	Center	487	687

Visual field by response

$p < .005$

		Responding Hand	
		Left	Right
Visual Field	Left	619	600
	Right	592	607
	Center	591	584

APPENDIX E

Experiment 4: Significant effects in ANOVAs of reaction times for each task

Physical identity matching task

Effect	Significance Level
Stimulus type	$p < .001$
Task order by response	$p < .05$
Response order by response	$p < .001$
Response by visual field	$p < .005$

Name matching task

Effect	Significance Level
Task order	$p < .05$
Stimulus type	$p < .005$
Response order by response	$p < .001$
Task order by visual field	$p < .025$
Response by visual field	$p < .05$
Task order by response order by response	$p < .025$
Response by visual field by stimulus type	$p < .001$
Task order by response order by response by visual field by stimulus type	$p < .025$

APPENDIX F

Experiment 4: Significant effects in analysis of percentage of errors

Effect	Significance Level
Task	$p < .005$
Response	$p < .05$
Task by stimulus type	$p < .005$
Task by visual field	$p < .05$
Visual field by stimulus type	$p < .05$
Task by visual field by response by stimulus type	$p < .025$

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