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# Differential Patterns of Interference During Concurrent Task Performance for the Two Cerebral Hemispheres

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# DIFFERENTIAL PATTERNS OF INTERFERENCE DURING CONCURRENT TASK PERFORMANCE FOR THE TWO CEREBRAL HEMISPHERES

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ABSTRACT

In this experiment differential hemispheric processing demands in four cognitive tasks, two verbal and two non-verbal, were measured using a simple reaction time probe procedure. The procedure also measured the interference between the reaction time probe and the verbal and non-verbal tasks. The method used was similar to that found in information processing research using a concurrent task procedure to measure processing demands during primary task performance (Posner & Boies 1971). In the concurrent task procedure the subject is requested to perform two tasks at the same time: a cognitive (primary) task and a reaction time probe (secondary task). The accuracy and speed of response to the unpredictable perceptual probe is used as a measure of spare capacity during the performance of the primary task that is available to be allocated to perceptual monitoring at the instant of probe presentation.

Four primary tasks were designed considering previous laterality research findings: two left hemisphere primary tasks (one requiring visual word processing and one requiring auditory word processing) and two right hemisphere primary tasks (one requiring visual-spatial processing and one requiring tone processing). Response to the primary task was pressing a switch with the right or left foot. The reaction-time probe tasks consisted of responding to stimuli presented to the right hemisphere with the left hand and stimuli presented to the left hemisphere with the right hand. The subjects responded to 26 randomly presented reaction time probes equally divided between right and left presentations. Twelve males

and twelve female subjects served in each modality. Each of the tasks was performed alone and concurrently. The subject was instructed to pay equal attention to both tasks.

Results showed that the male subjects tended to have shorter response latencies to the auditory reaction-time probes and female subjects tended to have shorter response latencies to the visual reaction-time probes. In addition, males had faster response latencies when the visual probe was presented to the right hemisphere than the left. These data suggest that males and females differed in the subprocesses they used to perform these tasks, and that visual and auditory subprocesses are organized differently within the sexes.

Results during concurrent performance in the auditory activation task condition showed that the right foot interfered more with right hand performance and the left foot interfered more with left hand performance. These data suggest that the major source of interference between the activation task and criterion task was interference between motor components of the two tasks.

Major differences were found between the verbal and non-verbal primary tasks in the way they were time-shared with the probe task. Performance on the verbal primary tasks appeared to have priority over the reaction time probe while performance on the non-verbal primary tasks did not; performance on the verbal primary tasks improved during concurrent conditions and performance on the non-verbal primary tasks declined. The enhancement in performance on the verbal primary tasks was accompanied by a greater decrement in performance on the probe task than occurred for probes during the non-verbal primary tasks.

# CHAPTER I

# INTRODUCTION AND LITERATURE REVIEW

## The Development of the Concept of Brain Lateralization

The concept of brain lateralization and the systematic investigation of the specialized higher function of the cerebral hemispheres began with Broca's discovery that the left hemisphere plays a major role in the speech processes of right handed subjects (Broca 1865). His observations of patients with unilateral brain disease revealed that although the right and left cerebral hemispheres appeared nearly identical in structure, they were not functionally equivalent. However, these early clinical observations did little to reveal the role of the right hemisphere in mental processes. Then, with the discovery of penicillin prior to the Second World War, many soldiers who had sustained brain damage during the war survived. A series of careful studies concentrating on those patients with well-lateralized brain lesions began uncovering the complementary specialization of the right hemisphere. In addition, a direct and striking demonstration of the functional asymmetry of the human brain was provided by the research of Roger Sperry. In working with a small group of patients in which the main interhemispheric commissures had been severed as a treatment for epilepsy, he and his colleagues delineated the contrasting specializations of the two sides of the human brain (Gazzaniga 1970, 1972; Gazzaniga and Sperry 1967; Sperry 1974; Sperry, Gazzaniga and Bogen 1969). Further investigation of the functional asymmetry of the human brain has been carried out using neurally intact subjects. Today investigators employ dichotic listening, tachistoscopic and dual task techniques along with other, more physiological, techniques to investigate both the nature and the degree of laterality effects in normal individuals (Kimura 1967, McKeever and Huling 1971, Studdert-Kennedy and Shankweiler 1970, and White 1969).

## Lateralization in the Brain Damaged Individual

The first evidence that the cerebral hemispheres might be functionally different came from systematic observations of brain damaged patients. These clinical observations revealed that patients with damage confined to one hemisphere tended to show a consistent pattern of behavioral deficits, while patients with damage confined to the other hemisphere showed a different pattern of behavioral deficits. In general, it was found that damage to the left hemisphere appeared to interfere more with the patient's verbal abilities and often produced various forms of aphasia (Hecaen 1969, McFie 1969). On the other hand, damage to the right hemisphere tended to interfere more with the patient's apprehension of complex figural patterns, sometimes leading to the inability to recognize faces and music (Bogen 1969).

Attempts to understand the mechanisms of hemisphere specialization have included consideration of unique information processing characteristics of the two hemispheres which may be relevant to the two hemispheres' differential cognitive capacities. Weinstein (1978), on the basis of experimental data from subjects with unilateral brain damage, argued that the right hand tends to have a bilateral representation for motor functions and the left hand only a contralateral representation. That is, the left hemisphere can control both sides of the body but the right hemisphere can only control the left side. In addition, he found that the right hand tends to have a relatively contralateral representation for somato-sensory functioning, and the left hand tends to have a bilateral and diffuse representation. Carmon (1978) studying perceptual asymmetry, found that the left hemisphere excels in the ability to recognize temporal sequences while the right hemisphere treats patterns as unitary pieces of information. Finally, DeRenzi (1978) asserted that the capacity to imagine space is dependent on a definite neural substrate and is asymmetrically represented in the two hemispheres. He based his assumption on the fact that unilateral neglect is found almost exclusively among patients with right hemisphere injury and visual field defects. The phenomenon of unilateral neglect suggests that in the left hemisphere there is only a mental image of the contralateral (right) field whereas in the right hemisphere both sides are represented. It follows that damage to the right side leaves the brain unaware of the presence of the left side, although damage to the left side can be compensated for by the duplicate representation of the right field laid down in the right cortex.

Semmes (1968) suggests that the different cognitive functions of the two hemispheres may be traceable to specialized forms of neural organization. In the left hemisphere, similar functional units are concentrated within a small area. This local representation permits precise coding of input and finely modulated control of output. As for the right hemisphere, unlike functional elements are concentrated within small areas.

Semmes suggests that the diffuse organization of the right hemisphere makes heteromodal integration possible.

The many methodological and theoretical problems of drawing inferences from studies of brain damage have been discussed in depth by Head (1926), Goldstein (1948) and Luria (1970, 1972). The methodology relies on observation and testing of patients with damage confined to one hemisphere. The performances of these patients are either compared to the performances of neurally intact matched controls or to the performances of patients with damage confined to the other hemisphere. When particular functions are found to be missing or diminished, it is inferred that the lost functions have been localized in the damaged hemisphere. Also, inferences about lateralization are drawn from comparisons between subjects rather than between hemispheres within an individual. Furthermore, the validity of generalizing from brain damaged individuals to the neurally intact individual has not been established. Major problems with this approach include small subject pools and the difficulty of determining the extent and location of the lesion.

## Lateralization in Commisurotomy Patients

The most well known evidence for lateralization of functions within the brain came from observations of epileptics in whom the corpus callosum had been severed to prevent the spread of electrical disturbances to the other side of the brain (Sperry 1961). Early research using these individuals as subjects revealed that the disconnected left hemisphere appeared dominant for speech, writing and calculation while the right hemisphere was unable to respond in speech or writing in the great majority of test situations. Despite this inability to communicate verbally, the disconnected right hemisphere appeared to excel in the apprehension and processing of spatial patterns, relations and transformations. As the methodology became more sophisticated, the prevailing view of the right hemisphere's verbal ability changed. From later research data (Gazzaniga 1970, 1972; Gazzaniga and Sperry 1967; Sperry and Gazzaniga 1967; Sperry, Gazzaniga and Bogen 1969) it was inferred that the right hemisphere does possess considerable receptive verbal skills although these are certainly inferior to the left hemisphere's verbal skills. Perhaps the most startling finding using this method has been the discovery that each of the hemispheres can apparently function independently when they are not connected (Gazzaniga 1972 and Sperry 1968).

In the two research methods using "split-brain" subjects, researchers rely on the anatomical structure of the brain to study lateralized functions. More specifically, in the case of visual stimuli, these methods rely on the neurological division of the visual image as it falls on the retina. That is, a visual stimulus appearing in an individual's right visual half-field will fall on the left side of the retina. Optic nerve fibers from both the left side of the left eye and the left side of the right eye project to the left occipital lobe. Thus, the information in the right visual half-field is projected to the left hemisphere and stimuli in the left visual half-field is projected to the right hemisphere. In the normal individual this information is integrated via the intact corpus callosum. Sectioning the corpus callosum eliminates this normal integration of sensory information, leaving each hemisphere with an independent source of information. Researchers argue that all the perceptual and cognitive functioning must take place within the hemisphere that receives the information.

The method used by Sperry and his students makes use of both the separate pathways in the visual modality and the fact that motor activity is controlled by the motor cortex located in the contralateral hemisphere. Sectioning the corpus callosum prevents information about motor responses from being transferred between hemispheres; only the motor area controlling the hand contralateral to the hemisphere receiving the information will have access to the information necessary to make a correct response. Therefore, it is assumed that perceptual and cognitive processing of the stimuli and the control of the motor response to the stimuli are confined to a given hemisphere. Completion of a given task implies the competence of that hemisphere to perform the task. Differences in accuracy and in reaction times between the hemispheres are interpreted as differences in ability to perform a task. For example, to measure the verbal competence of the right hemisphere, a subject may be asked to feel an object with his left hand and then asked to point to the object's name with his left hand or a word may be presented in the left half-field and the subject asked to retrieve the object from a group of objects with his left hand.

Levy's (Levy & Trevarthen 1976, Levy, Trevarthen & Sperry 1972) method to study lateralization also depends upon the anatomy of the split-brain subject. In this line of research, different stimuli are projected to the two hemispheres at the same time. Depending upon which type of response is required from the subject, one hemisphere usually dominates processing the stimuli within its visual half-field and initiates the response. Levy found when a verbal response was required, the stimulus in the right visual half-field was processed, and when a non-verbal response was required, the stimulus in the left visual half-field was processed. From these behaviors, both Levy and Sperry concluded that the left hemisphere was dominant for verbal materials and the right hemisphere was dominant for non-verbal materials.

Even though studies using "split brain" individuals as subjects show fairly consistent differences between the hemispheres in terms of the information they process most efficiently, many methodological and theoretical problems are evident (Nebes 1978). As with the methods using brain damaged individuals, the results should be regarded with caution for several reasons. The subjects' presurgical functioning is usually not well-characterized and can be expected to have been abnormal due to the epileptic symptoms. One major theoretical question is raised by the ability of the hemispheres to function independently: do the cerebral hemispheres function differently when they are independent? Gazzaniga (1972) suggests that the contribution made by a hemisphere during independent functioning is not the same as its contribution during integrated functioning.

Another problem is evident when the attempt is made to integrate findings from research on brain damaged patients with that on split brain subjects. Each of these methods contributes conflicting data about the verbal ability of the right hemisphere. Data from the "split brain" subject suggest that each hemisphere has some verbal ability. On the other hand, data from brain damaged individuals suggest that brain functioning is strictly localized and the right hemisphere has little language ability. Moscovitch (1973) has attempted to resolve this theoretical conflict by suggesting that both hemispheres have verbal ability but the left hemisphere overshadows and inhibits the right hemisphere during verbal performances even when it is unable to perform the task itself due to brain damage.

## Lateralization in the Neurally Intact Individual

The two main research methodologies using neurally intact subjects also take advantage of the anatomically separate pathways from both the ear and the eye to each of the cerebral hemispheres. One method relies on the instantaneous presentation of visual stimuli with a tachistoscope to one visual half-field. The other method relies on competition between auditory stimuli delivered to one ear with different auditory input delivered to the other ear (dichotic listening). These studies have confirmed the findings that certain abilities or capacities are lateralized within the human brain. It is found that words are more accurately recognized by the left hemisphere and faces are more accurately recognized by the right hemisphere in studies employing a tachistoscope; the left hemisphere appears dominant for spoken prose and the right hemisphere appears dominant for music in studies employing dichotic listening.

### Tachistoscopic Techniques

The majority of studies using neurally intact subjects have investigated the processing of visual information. In these studies visual stimuli are presented in either the left visual half-field or the right visual half-field. With rapid presentation of visual stimuli, the individual cannot scan the whole visual field and the information in each half-field is projected to different hemispheres. It is assumed that for information to reach the other hemisphere, it must traverse the corpus callosum. If the individual's response to information presented in one visual half-field takes longer or is less accurate than their response to the same stimuli presented in the other visual half-field, then it is inferred that the information had to be transferred via the corpus callosum and processed by the other hemisphere or that the information was retained and processed by that hemisphere but the processing was less efficient or inferior to the other hemisphere (Kimura 1966).

Several critiques of this method have posed more questions than they have answered (Harcum 1978, and White 1969). Harcum (1978) states that even though results confirming those found in brain damaged individuals and in individuals in whom the corpus callosum has been severed are often quoted, many other studies have shown no differences found in bilateral presentation of stimuli are opposite to that predicted by theory and are explained by appealing to the scanning strategy of the individual (Heron 1957). Harcum (1978) performed an in depth survey of studies using unilateral and bilateral presentation of verbal stimuli. He presents a cogent argument that lateral asymmetries result from differences in the information processing dynamics of the individual rather than different hemispheres being structurally more capable of handling different classes of stimuli as Semmes (1969) advocates. He bases his argument on research findings indicating that the dynamics of information processing often varies according to subject and response variables as well as the verbal nature of the stimuli. In an earlier review, White (1969) concluded that multiple variables influenced the laterality of visual processing. In general, the evidence suggests that the actual physical characteristics (verbal vs nonverbal) of the stimulus and the response do not completely determine the laterality of the processing.

Several techniques used in this method have been criticized. Using inferred neural transit times as a part of the rationale is not appropriate. Swanson, Ledlow, and Kinsbourne (1978) in a review of interhemispheric transit time studies, concluded that the attempts to measure interhemispheric transit times showed results that were too variable to provide a good estimate of these physiological reaction times; many other factors seem to overshadow the time taking in crossing the structural link. One such factor (Simon, Hinricks & Craft (1970) is the spatial location of both the stimuli and the response. Additionally, the instantaneous presentation of stimuli to peripheral visual fields has been criticized by Trevarthen (1970). He asserts that the processing of stimuli in the peripheral visual field is different from processing in the central visual field. In addition, the individual does not deal extensively with information that is presented instantaneously in one of his visual fields. Although lateralizing visual input with normals via the visual half-fields has provided valuable information, this method may be limited in the contributions it can make to the study of lateralization.

## Dichotic Listening Techniques

Another major approach to the study of brain lateralization in the neurally intact individual involves the processing of auditory information. The rationale for this method is also based on anatomical considerations. Even though each ear has connections with the auditory receiving areas of both cerebral hemispheres, the contralateral connections are apparently more effective than the ipsilateral pathways (Bocca, Calearo, Cassinari and Mighavacca 1955, Kimura 1967).

In research mbased on this method, different auditory messages are delivered simultaneously to each ear via stereo headphones. It is inferred (Kimura 1967) that the information traversing the contralateral pathway occludes the information arriving along the ipsilateral pathway and thereby enhances the advantage of the contralateral pathways. Thus, the message delivered to each ear is projected mainly to the contralateral hemisphere. For a hemisphere to have access to information from the ipsilateral ear, the information must be transferred to that hemisphere via the corpus callosum. Lateral dominance is inferred when information presented to one ear is processed faster or more accurately than when this same information is presented to the other ear. That is, either the information has been transferred to the other hemisphere for processing or the hemisphere receiving the information is less efficient at processing that type of auditory stimuli. Two major variations have been used, either the subject attends to only the message delivered to one ear or he attends to both messages at the same time. In most studies, responses consist either of recalling the message or detecting a target.

Researchers are uncertain, however, about whether dichotic listening techniques are necessary for ear superiority to be manifest. The major question is whether the contralateral pathways are strong enough to produce ear superiority in the absence of competition between stimuli. A recent study has found that a monaural ear advantage for certain tasks (Catlin, VanDerveer, and Teicher 1976) which does not differ significantly from that found in dichotic listening. Until there is direct information available about what happens when the alternative (ipsilatteral) pathways are not available (assumed in dichotic listening), the interpretations of ear advantages in dichotic listening will be tentative.

In addition, generalizing from dichotic listening to everyday behavior may not be valid; the individual does not normally have different messages arriving at each ear simultaneously. The same concerns that apply to visual perception research apply to auditory perception research. The number of subject, stimuli, response, and situation variables that affect the subjects' performance make it difficult to limit or control the sources of variability. These sources of variability are potential sources of contamination in auditory research on lateralization.

Dual Task Techniques

The dual task technique is a relatively recent method of investigating laterality. In this method, the subject attempts to perform two tasks at the same time. Usually, one task is a cognitive (information processing) task and the other a lateralized motor task; the subject listens reads or vocalizes one task while either hand is performing another task. Most studies find that concurrently performing a verbal task impairs motor performance of the right hand more than that of the left.

In early studies, researchers combined two tasks putatively mediated by different hemispheres to test the hypothesis that tasks performed in different hemispheres would not interfere with each other. Broadbent and Gregory (1965) asked subjects to simultaneously respond manually to touch and verbally to spoken stimuli. They found that even though these two tasks called on specialized functions of the two hemispheres, the tasks interferred with each other. The first step toward quantifying this method was taken by Allport, Antonis and Reynolds (1972). They had subjects shadow speech and sight music at the same time. The interference between these tasks was less than would be expected from two simultaneous speech messages. A noval approach (Kinsbourne and Cook 1971) had the subject repeat a sentence while balancing a dowel with one hand.

Concurrent verbal task performance depressed right hand balancing and enhanced left hand balancing. Hicks (1975), Briggs (1975) and Johnson and Kozma (1977) have replicated these results for the right hand but not for the left. Lomas and Kimura (1976) have failed to replicate this study. In these studies, task performance by either hand did not interfere with the verbal task.

Other techniques have been used to measure interference between tasks. Beaton (1979) had subjects perform two simultaneous sorting tasks, one with each hand, while verbal input was provided to the right visual half-field or to the left visual half field; a complex interaction was observed between visual half field, hand and tasks. Botkin, Schmaltz and Lamb (1977) requested the subject to repeat digits backward while trying to hold the hand still. A nine hole steadiness tester measured hand performance. Using the right hand interfered with the task but no interference occurred for the left hand. In both of these studies, the verbal task interfered with hand performance.

In another group of studies, finger movement was used as the motor task. Hicks, Provenzano and Rybstein (1975) used finger sequencing combined with a verbal task. They found a bilateral though asymmetric reduction in motor performance, with the right hand more impaired than the left. In two recent studies (Bowers, Heilman, Satz and Altman 1978, and McFarland and Ashton 1978), interference from both verbal and non-verbal tasks was examined. The subject was requested to perform either a verbal or non-verbal task while tapping with the finger. Both researchers found that the verbal task depressed right hand finger tapping more than left hand finger tapping, and non-verbal tasks interfered with both hands.

There are limitations to the methods in these studies. The subject has control over scheduling the performance of one or both concurrent tasks. This allows timesharing. One hand is tested at a time; there is thus no indication of the processing taking place in both hemispheres at the same time. In addition, responses to the material presented occurred after the concurrent performance was over, requiring a substantial memory load.

The methodology used in the dual task lateralization research is similar to that found in research using the concurrent task procedure to measure processing demands during primary task performance (Michon 1964, 1966). In the concurrent task procedure, the subject is requested to perform two tasks at the same time; one is a cognitive (primary) task, the other a reaction time probe (secondary task). The accuracy and speed of response to the unpredictable perceptual probe is used as a measure of the spare capacity available during the performance of the primary task that is allocated to perceptual monitoring at the instant of presentation.

In measuring the interference between dual, putatively lateralized tasks, researchers (Botkin et al. 1977, Bowers et al. 1979, Franco 1977, Kinsbourne and Cook 1971, and McFarland and Ashton 1978) appear to be measuring the spare processing capacity available for secondary task performance in each of the cerebral hemispheres after processing of a cignitive task. The findings of these researchers can be formulated using an attentional or limited capacity model. If the subject performs simultaneously two tasks both requiring processing within the same hemisphere, that hemisphere's processing capacity would be overloaded and performance on the secondary task would be affected. If the processing demands of the secondary task were transferred to the other hemisphere without changing the absolute processing demands of either task the limited processing capacity of neither hemisphere would be overloaded and performance on both tasks would improve.

Possible laterality effects have also been found in studies using concurrent task methodology to study processing demands. For instance, McLoed (1976) found that different probes (i.e., left hand vs vocal responses) gave a different picture of the processing demands of a task. The data suggests that the different probes (left hand vs vocal) were measuring the demands placed upon the different hemispheres during the same task. In other words, the probe with a verbal response was measuring the demands placed on the left hemisphere during performance of the cognitive task and the probe with the left hand motor response was measuring the demands placed on the right hemisphere during the same task. These studies taken as a whole support the development of a concurrent task procedure to measure lateralization of specialized higher functioning within the neurally intact individual.

## Concurrent Task Methodology

The concurrent task procedure can be conceptualized in terms of an attention or limited capacity model of the human brain (Kahneman 1973). In greatly simplified form, this model postulates a limited processing capacity within the brain and predicts that interferences will occur when two tasks are performed simultaneously even when these two tasks do not share mechanisms of either perception or response. This procedure has been used primarily to study the demands on processing capacity during learning of or performance on different tasks (Posner and Klien 1973) and to delineate the time course of demands on processing capacity.

Of all the types or probes used to measure variations in spare processing capacity during performance on a primary task, the reaction time probe (Posner and Boies 1971 and Posner and Klien 1973) appears to be the best suited for measuring the processing demands of lateralized cognitive tasks. In adapting this procedure to investigate lateralization the same considerations apply as those in the original technique. To obtain a measure of spare capacity, the probe must be introduced at an unpredictable time (Dick 1974). In addition, the fact that structural interference can occur when the tasks occupy the same mechanism of perception or response (Treisman and Davis 1972 and Brooks 1968) must be taken into account.

## Summary

The large amount of material generated by the research on lateralization remains unintegrated at a level deeper than the verbal - non-verbal and other global dichotomies now delineated. In addition, the current methodologies used to investigate lateralization of cognitive functioning in the neurally intact individuals suffer from many theoretical and methodological problems.

It is proposed that a concurrent task procedure could be employed as an alternative approach to investigate the lateralization of both elementary and specialized higher functions within the neurally intact subject. In essence, this procedure is based on the observation that people cannot perform two tasks at the same time without some interference occurring between the two tasks. In adapting a concurrent task procedure to the study of lateralization, it is assumed that (1) the brain has two channels of processing, one in either hemisphere (Kerr

1973) rather than one channel of processing (Kahneman 1973), (2) the performance of any task requires a prescribed set amount of processing capacity within each hemisphere, (3) tasks can be designed to require a relatively greater amount of processing in one hemisphere compared to the other hemisphere, (4) the individual has a limited amount of processing capacity within each hemisphere and (5) if he tries to perform more than one task which requires a major portion of its processing to take place within the same hemisphere there will be a performance decrement on one or more of the tasks.

## Statement of the Problem

The specific purpose of the present research was to validate the use of the concurrent task procedure to study the lateralization of specialized functions in the neurally intact individual. The method involved measuring differential hemispheric processing demands in four cognitive tasks (primary tasks) using a simple reaction-time probe (secondary task) procedure. The four activation (primary) tasks, two visual and two auditory tasks, were constructed taking into account previous laterality research findings. Evidence from laterality studies within the visual modality indicates that non-verbal spatial tasks require right hemisphere processing, therefore, a task that required monitoring the relationship between positions of stimuli in space was constructed to be the right hemisphere visual task. In addition, these same studies indicate that the left hemisphere is dominant for verbal stimuli, thus a task requiring the monitoring of a series of written words (numbers) was constructed to be the left hemisphere visual task. The auditory tasks were based on evidence from dichotic listening studies. These studies indicate that the right hemisphere is dominant for non-verbal stimuli such as music, thus a task requiring the monitoring of the relationship between a series of piano tones was constructed for the right hemisphere auditory task. Dichotic listening studies also indicate that the left hemisphere is dominant for verbal stimuli, thus a task requiring the monitoring of a relationship between a series of spoken numbers was constructed to be the left hemisphere auditory task.

In designing these tasks, consideration was given to the possibility that during concurrent performance the brain could switch from one task to the other with little interference occurring between the tasks. This switching could occur if both the tasks being investigated could be organized into discrete tasks separated in time. Therefore the activation tasks were designed to require continuous processing of the stimuli.

To validate these activation tasks, the simple reaction time procedure was selected not only because as a measure it is sensitive to the processing demands of other tasks but also because this task can easily be designed to require processing capacity confined to one hemisphere. The criterion (secondary) task to be used in validating the visual activation task required the subject to respond to a tone presented to either ear by pressing a button with the ipsilateral hand. Research findings indicate that processing is confined to one hemisphere in this task (Murphy and Venables 1970). The criterion (secondary) task validating the auditory task required the subject to respond to a light presented in either visual half-field with the ipsilateral hand. Research findings indicate that processing is confined to one hemisphere in this task (Filbey and Gazzaniga 1969, Moscovitch and

Catlin 1970). These criterion tasks were designed to be presented at unpredictable points during the performance to avoid the problem of sequential processing (Dick 1974). This procedure prevented the subject from arranging processing of the secondary task at certain times to avoid interference from the primary task. Also, the validation task was designed so that it would not interfere with the subjects' perception of or response to the activation task (structural interference). When the subject was performing the visual activation tasks the criterion task was presented in the visual mode. Responses to the activation task were made by the subjects with their foot while the responses to the criterion task were made by the subjects with their hands.

It was predicted that when a right hemisphere activation (primary) task was performed simultaneously with the criterion (secondary) task the activation task would interfere more with the responses of the left hand. Conversely, when a left hemisphere activation (primary) task was performed simultaneously with the criterion (secondary) task, the activation task would interfere more with the responses of the right hand. These predictions were based on the assumption that greater performance decrements would occur when both tasks make major processing demands on the same hemisphere than when these demands were divided between the hemispheres.

## CHAPTER II

## METHOD

### Design

The specific purpose of the present experiment was to validate the concurrent task procedure as a method of investigating laterality of specialized higher functions. This was accomplished by employing tasks that are putatively mediated by primarily one hemisphere. Two right hemisphere and two left hemisphere activation tasks were used as primary tasks and two perceptual-motor tasks as secondary tasks. The processing demands of each activation task was assessed by comparing performances of the right and left hemispheres on the criterion task during concurrent performance with the corresponding activation task to performance of the right and left hemispheres during separate performance. Each activation task was validated independently using a 2 (concurrent vs separate) by 2 (right vs left hemisphere) repeated measures design with repeats on both measures.

### Subjects

Forty eight right-handed students served as subjects in the present experiment. One half of the subjects, 12 male and 12 female, were used to validate the visual activation tasks. The other half of the subjects, 12 male and 12 female, performed in the auditory activation task condition. One-half of the male subjects and one-half of the female subjects used their right foot to respond to the activation task and the other half used their left foot. The subjects were volunteers recruited from freshman and sophomore level classes in Psychology. They received class credit for their participation.

## Apparatus and Tasks

Four different activation tasks were constructed based on specialized higher functions that were found to be lateralized in previous laterality research. In addition the tasks were constructed to be as analogous possible. They all had the same number of correct responses in the same temporal sequence.

### Visual Right Hemisphere (non-verbal) Activation Task

The visual activation task designed to differentially engage the right hemisphere was a spatial task requiring a motor response. This task required monitoring the relative position of a series of .1 inch squares presented over time through a 1 x .2 inch slot. The square could appear in any one of 10 contiguous horizontal positions delineated by graph paper. The sequence of positions in which the square appeared was determined using a random number table with the constraint that two consecutive squares would not appear in the same position. The squares were placed at the appropriate intervals on a strip of graph paper which wound around a memory drum. The subject saw the squares move through the slot one at a time at a rate of either 1 per second or 2 per second. The subject was to respond by pressing a foot pedal whenever the square shifted horizontally in the same direction twice in succession. The subject responded to both right and left displacements. After each response, the subject was to begin searching for a new sequence of three squares. That is, the subject did not respond to overlapping sets. The foot of response was counterbalanced across subjects.

The stimuli were placed on a continuous strip of graph paper with black ink. The tape contained one three minute practice set where stimuli were presented at a rate of one/two seconds, one three minute practice set presented at a rate of one/second and one four and one-half minute set for use in the experimental conditions (also presented at a rate of one/second).

The experimenter sat beside the subject and counted the squares into a microphone. The subject wore earphones during the whole experiment so that he/she could not hear the counting. These numbers plus the subject's foot responses were both recorded on the same stereotape. The responses were scored from the tape at a later time. A criterion of 50% correct responses on the practice set was established for retaining the individual in the experiment.

Visual Left Hemisphere (verbal)
Activation Task

The visual activation task designed to differentially engage the processing capacity of the left hemisphere was a verbal task with a motor response. This task required monitoring a sequence of printed number names between zero and nine and used the same apparatus as described above. The random sequencing was the same as in the non-verbal task. It was generated using a random number table with the constraint that no two consecutive numbers would be the same. The number names were constructed of .1 inch letters and always appeared in the same horizontal position. The subject could see one number at a time as the numbers moved through the slot and responded by pressing the foot pedal when any three successive numbers formed a sequence of increasing or decreasing values. As in the previous task, the subject did not respond to overlapping sequences. The foot of response was counterbalanced across subjects.

Two practice tapes and one experimental tape were prepared as in the visual right hemisphere activation task. During the session, responses were recorded using the same procedure as that used in the non-verbal task, with the same 50% criterion in the one number per second practice set required for retaining the subject.

Auditory Left Hemisphere
(verbal) Activation Task

The auditory activation task, designed to differentially engage the left hemisphere, was constructed analogously to the visual left hemisphere activation task except that the numbers were presented auditorily from a previously recorded tape. The three randomized number series were the same series as used in the previously described tasks. The numbers, spoken by a female, were recorded on a stereo tape recorder with interstimulus intervals of two seconds for one practice set and one second for the other two sets. The intervals were regulated by a metronome set at one beat per second. The number series were delivered via stereo headphones to both ears at a loudness level of 50 dB. The experimenter sat beside the subjects and recorded their responses on an answer sheet. The 50% criterion was used for retaining the individual.

Auditory Right Hemisphere
(non-verbal) Activation Task

The auditory task designed to differentially engage the right hemisphere's processing capacity required monitoring a random series of piano tones. This task, constructed analogously to the other three activation tasks, consisted of a random series of the piano notes D,F, G,A, middle C,D,F,G,A, and B (listed in order of increasing frequency). The tones were all separated in frequency by either one or one and a half steps and in time by 200 msec. In performing the task, the subject searched the series of tones for sets of three consecutive tones either increasing or decreasing in frequency. Upon hearing a set, the subject responded by pressing a foot pedal. As in the previous task the subject did not respond to overlapping sets.

The tones were recorded on audio tape with a stereo tape deck. To facilitate recording of the tones, three number sets prepared according to the procedure used in recording number sets in the auditory left hemisphere task were delivered to the experimenter via head phones. Upon hearing a number the experimenter struck the appropriate piano key (each number corresponded to a tone) placing a tone of approximately 800 msec duration on the tape. Three sets of tones, identical in length and interstimulus interval to those in the other three activation tasks were constructed. During the experiment, the tones were delivered via headphones to both ears at a loudness level of 60 dB. The responses were recorded in the same manner as the verbal auditory activation task and the subject was required to meet the same performance criterion as in the other three activation tasks.

Auditory Criterion Task

The auditory criterion task (to validate the visual activation task) was a perceptual-motor reaction time task drawn from concurrent task procedure. The perceptual component of the task consisted of a series of short (200 msec) tones presented monaurally in a random left-right ear sequence. In performing the manual response, the subject was required to press a switch with the hand ipsilateral to the ear in which the tone was heard. The earphones were counter balanced across subjects.

The tones comprising the auditory criterion task were recorded on audio tape with a stereo tape deck prior to the experimental sessions. The interstimulus intervals (averaging 8 seconds between the tones) were generated by a variable interval timer constructed for this purpose. Upon a signal from the timer, the appropriate ear channel in the randomized left-right sequence was chosen on an audiometer (
At the same time, the bar on the audiometer was pressed for approximately 200 msec placing a 750 Hz tone on the tape. This procedure was repeated for a total of 26 tones (13 on the right ear channel and 13 on the left ear channel). This procedure resulted in a continuous, four and one-half minute tape of 750 Hz tones of 200 msec duration with intertone intervals averaging eight seconds.

During the experimental session, the tones were delivered from an adjacent room via stereo headphones at a loudness level of 60 dB. The electrical impulse which generated the tone also triggered a tone activated switch ( ) starting a reaction timer ( ). Both these instruments were located in the adjacent room. When the subject heard the tone, he/she responded by pressing the appropriate switch. The two switches were placed 10 inches apart on either side of the apparatus which delivered the visual activation task. This response opened the circuit and stopped the reaction timer. The reaction time was recorded and the timer reset by an assistant.

Visual Criterion Task

The visual criterion task chosen was a perceptual-motor task also drawn from concurrent task procedure. In this task, the perceptual component was a series of light flashes in either the left or right visual half-field delivered in a random right-left sequence (lateralized lights). The motor response required the subject to press a switch with the hand ipsilateral to the visual half-field in which the light flashed.

During the experimental sessions the series of light flashes was presented via a pair of 9 volt light bulbs mounted nine inches apart on a black panel placed 2 feet in front of the subject at eye level. All the other equipment was located in an adjacent room. The interstimulus intervals between light flashes averaged eight seconds and were generated by a variable interval pulse formerly constructed for this purpose. The pulse also advanced a stepper which determined, according to a preset random sequence, the random right-left visual half-field series. When the subject saw the light he/she responded by depressing the appropriate key. The two key switches were placed 12 inches apart and nine inches below the light bulbs on a table. Pressing the appropriate key broke the circuit and stopped the reaction timer. The reaction time was recorded and the timer reset by an assistant located in the adjacent room.

## Measurement

The primary measure in this experiment was the median reaction times of subjects in the visual activation task condition and of subjects in the auditory activation task condition. In the visual activation task condition, the reaction times of the right hand to a tone presented to the right ear (left hemisphere performance) and the reaction times of the left hand to a tone presented to the left ear (right hemisphere performance) were measured. The subjects' performance on the auditory criterion task was measured both alone and during concurrent performance with each of the visual activation tasks. Thus, each subject in this condition had eight measures: the median reaction time of the right hand and the median reaction time of the left hand on the criterion task alone for each of two (verbal and non-verbal) sessions and the median reaction time of the right hand and the median reaction time of the left hand on the criterion task during concurrent performance with each of the two visual activation tasks (verbal and non-verbal).

In the auditory activation task condition where concurrent performance was with the auditory activation tasks (verbal and non-verbal), the same reaction times were measured except the subject was reacting to lateralized light flashes rather than lateralized tones.

Of secondary interest was the subject's performance on each of the activation tasks. On these tasks, performance was measured by the number of correct responses. The subject's performance was measured on each of the activation tasks both alone and during concurrent performance with the criterion tasks.

## Experimental Setting

The subject performed all the tasks seated at a 2 by 5 foot table in a quiet 7 by 7 foot room with no windows. In the auditory activation task condition, the board in which the lights were mounted was positioned 2 feet in front of the subject. Placed 9 inches below the lights were the two keys mounted 10 inches apart in a 12 by 5 by 2 inch box. The keys were positioned one foot from the edge of the table to allow the subject to rest his/her arms on the table while performing the task. In the visual activation task, the memory drum was positioned on the table directly in front of the subject. The two keys, mounted in small boxes were placed on the table one on either side of the memory drum. The boxes, 10 inches apart, were positioned one foot from the edge of the table to allow the subjects to rest their arms on the table. The foot pedal was placed on the floor directly in front of the subject. During performance on the activation tasks, the experimenter sat beside the subject and used the same table to record the subject's responses either on a score sheet or into a microphone depending upon the condition.

## Procedure

When the subject arrived for the experiment, they were taken into the experimental room, seated at the table, and given a consent form to sign (see appendix ). The subjects were told that the purpose of the experiment was to find out how well people could do two tasks at the same time. They were also told that they would be given practice on each of the tasks separately and together before they were required to perform them together in the experimental condition. The subject was then instructed in the appropriate activation task. Within each modality, one-half of the subjects were administered the left hemisphere task first. Within each of these conditions, one-half of the subjects used their right foot and one-half of the subjects used their left foot to respond to the activation task.

All the experimental sessions followed the same format. The procedure and instructions for the auditory left hemisphere activation portion of the study is given as a prototype for each of the experimental sessions. Instruction in the task was begun by telling the subject "You will hear a random series of numbers between 0 and 9 at intervals of two seconds via these earphones. Listen for increasing or decreasing sequences of three numbers. In other words, when any three successive numbers form a sequence of increasing or decreasing values, press the foot pedal before the next number. After you respond--that is, after a sequence of three increasing or decreasing numbers--start searching for a new series. You are not to respond to overlapping sets. For example, if you hear the numbers 1,2,5,6,3,7,9 you should respond only after the 5 and the 9."

After the instructions were given, the subject was administered the first practice set of the activation task which was two minutes in duration with numbers presented every two seconds. After a 30 second rest interval the subject was administered the second practice set which was three minutes in duration with numbers presented every second. Next performance on the activation task after practice was measured. This baseline set was four and one half minutes in duration and was presented at a rate of one number per second. If the subject did not reach the criterion of 50% accuracy, he/she was released from the experiment at this point.

Immediately following completion of this portion of the experiment the subject was introduced to the criterion task. He/she was instructed as follows, "one of these two lights will flash, when it does you are to press the switch under the light. Keep your eyes fixed on the fixation point and don't shift your eyes to look at either light. That is don't look at the light when it comes on. The lights will flash in a random right-left sequence and at variable time intervals averaging eight seconds. Press the key as quickly as you can. The set will last for four minutes." After these instructions were given, the subjects responded to the light flashes for six minutes and his/her responses were recorded. The first 10 reaction times were discarded from the analysis.

Before performing the activation and the criterion tasks simultaneously, the subject was told "Now we want to see how well people can perform both tasks at the same time. You will be given some practice at performing both tasks together. Do each task exactly as you did it before. Both tasks are equally important so don't pay more attention to either one of the tasks." First the subject practiced the activation task and the criterion task concurrently for three minutes. Then after a 30 second break, the subject performed the auditory left hemisphere activation task and the visual criterion task together for four and one-half minutes. The verbal responses to the activation task and the reaction times to the light flashes were recorded. After completing the first portion of the auditory activation task condition which lasted approximately one-half hour, the subject was given an appointment to return in approximately one week for a second session.

During the second session the subject was administered the auditory right hemisphere activation task and the visual criterion task following a similar procedure to that described above and used in the first session. The other half of the subjects in this condition were administered the activation tasks in the reverse order. After completing both sessions, the subject was thanked for his/her participation and debriefed.

In the validation of the visual activation tasks, the subject was administered the tasks using a similar procedure as that used in validating the half hemisphere auditory activation tasks. (See appendix for instructions). Order of presentation of the tasks within modality was counterbalanced across subjects. Again, after completing both sessions, the subject was thanked for his/her participation and debriefed.

# CHAPTER III

# RESULTS

## Treatment of the Data

Before the data were analyzed the following treatments of the data sets were performed.

Obtaining per-subject Response Latencies on the Criterion Tasks. The procedure for collecting the data was the same for both the visual and the auditory criterion tasks. Thirteen response latencies for each hand were obtained during each subject's performance on the criterion task in each of four different conditions: performance of the criterion task both alone and during concurrent performance with the verbal activation task and performance of the criterion task both alone and during concurrent performance with the non-verbal activation task. To correct for the inherent skewness in reaction time data the median right and left hand reaction times for each subject during each of these conditions were used as the dependent measure for the analysis of variance. If the subject responded with either the wrong hand or both hands at the same time, the response latency was assigned a one second value for the correct hand. The median response times were all less than one second.

Scoring the Activation Tasks. The primary measure used to analyze performance on the activation tasks was the number of correctly identified series on each of the activation tasks. The maximum possible number of series on each of the activation tasks was 52. Occasionally within the task, there were overlapping series, e.g., 1 4 6 5 2, and if the subject responded to both the 6 and the 2 only one correct response was added to their score. If a subject indicated a series where there was none (a false positive) it was counted as an error. The number of false positive errors was small for all subjects so these data were not analyzed.

Analysis of Criterion Task Performance during the Auditory Number (left-hemisphere) Activation Task Condition. The performance of the criterion task alone and during concurrent performance with the number activation task was evaluated by means of a 2x2x2x2 repeated measures analysis of variance. The resulting analysis had as independent variables the between subject effects of Sex (male or female) and Foot of response to the activation task (right or left) and the within subject effects of Condition (separate or concurrent) and Hemisphere of response on the criterion task (right or left). Table 1 shows the means and standard deviations covering major conditions. There appeared to be a large difference between the variances of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, $F$= 7.32, df= , , p=

The results of the repeated measures ANOVA are summarized in Table 7 in the appendix. The results do not support the hypothesis that the number task interferes relatively more with left hemisphere than right hemisphere performance on the criterion task during concurrent performance.

TABLE 1

MEAN REACTION TIMES AND STANDARD DEVIATIONS FOR PRESENTATION TO RIGHT AND LEFT HEMISPHERES FOR SEPARATE AND CONCURRENT PERFORMANCE ON THE VISUAL CRITERION TASK IN THE LEFT HEMISPHERE ACTIVATION TASK CONDITION

| | | Separate | | | | Concurrent | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Left | | Right | | Left | | Right | |
| Sex | Foot* | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD |
| Female | Right | 436.3 | 99.5 | 426.8 | 110.5 | 590.5 | 71.9 | 577.8 | 73.8 |
| Female | Left | 383.7 | 73.6 | 393.3 | 78.9 | 521.2 | 84.9 | 515.2 | 98.5 |
| Male | Right | 422.0 | 88.7 | 392.0 | 83.9 | 577.0 | 69.5 | 509.2 | 47.38 |
| Male | Left | 513.5 | 122.6 | 497.2 | 128.2 | 572.0 | 88.6 | 593.5 | 65.9 |

*Foot of response on the activation task.

A significant F-value was obtained for the Condition main effect $F(1,16)=53.82$, $p<.001$. This expected result shows that the reaction times in the concurrent condition were longer than the reaction times in the separate condition; i.e., performing another task at the same time interferes with the speed of performance on the criterion task.

An unexpected result was a significant interaction between Sex and Foot of response, $F(1,16)=5.824$, $p<.05$ (shown in Figure 1). Post hoc Newman-Keuls comparisons between means of simple main effects revealed that males who used their left foot to respond to the activation task had longer response latencies than females who used their left foot. These males also tended to have longer response latencies than males who used their right foot to respond to the activation task.

The Foot of response and Hemisphere interaction was also significant, ($F(1,16)=4.53$, $p<.05$ (shown in Figure 2). Post hoc Newman-Keuls comparisons between means of simple main effects revealed that

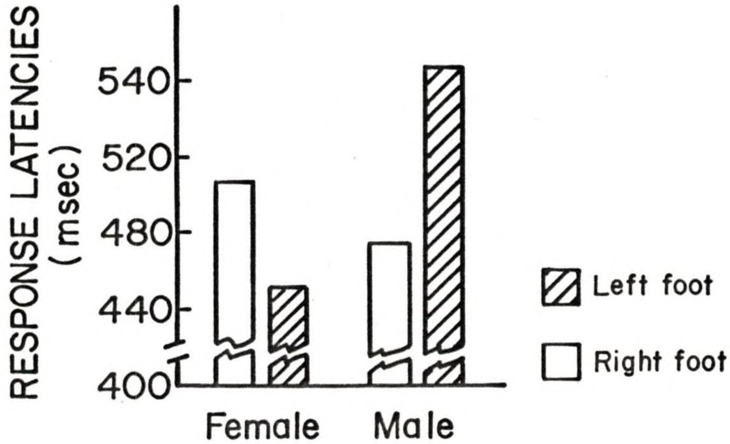


Fig. 1. Sex by Foot interaction during the auditory number activation task.

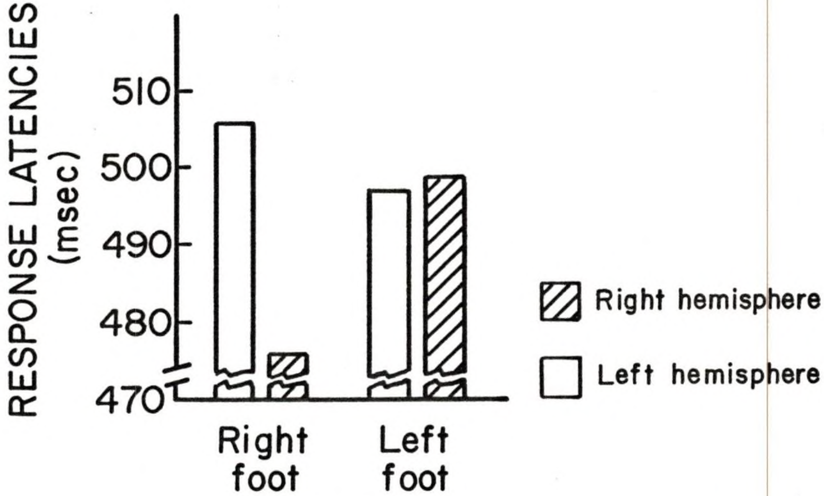


Fig. 2. Hemisphere by Foot interaction during the auditory number activation task.

the subjects who used their right foot to respond to the activation task had slower reaction times to left hemisphere presentations than right hemisphere presentations. Subjects using their left foot responded equally fast to left and right hemisphere presentations.

The data was analyzed for Order effects. Significant interactions were found between Sex and Order and among Sex, Order, and Condition (shown in Table 7). Inspection of the data revealed that males did better with the number task first and females did better with the number task second. For females, this held true for both separate and concurrent conditions and for males was only true for separate conditions. That is, in the concurrent condition for males there were no Order effects on performance.

<u>Analysis of Criterion Task Performance during the Tone (right hemisphere) Activation Task Condition</u>. The performance of the criterion task alone and during concurrent performance with the tone activation task was evaluated by means of a 2x2x2x2 repeated measures analysis of variance identical to that performed for the numbers task. The means and standard deviations of the data are shown in Table 2. There appeared to be a large difference between the variances of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, $\underline{F}$= 11.44, df=

$\underline{p}$=

The results of the repeated measures ANOVA are summarized in Table 8 in the appendix. The results do not support the hypothesis that the tone task interferes relatively more with right hemisphere performance than left hemisphere performance on the criterion task during concurrent performance.

TABLE 2

MEAN REACTION TIMES AND STANDARD DEVIATIONS FOR PRESENTATION TO RIGHT AND LEFT HEMISPHERES FOR SEPARATE AND CONCURRENT PERFORMANCE ON THE VISUAL CRITERION TASK IN THE RIGHT HEMISPHERE ACTIVATION TASK CONDITION

| | | Separate | | | | Concurrent | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Left | | Right | | Left | | Right | |
| Sex | Foot* | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD |
| Female | Right | 427.0 | 129.5 | 426.5 | 78.8 | 579.8 | 77.5 | 545.7 | 72.9 |
| Female | Left | 390.7 | 78.7 | 385.5 | 75.1 | 496.3 | 52.0 | 507.7 | 51.9 |
| Male | Right | 446.8 | 91.8 | 416.0 | 75.8 | 562.0 | 45.0 | 519.0 | 64.2 |
| Male | Left | 513.3 | 152.2 | 494.0 | 151.6 | 524.7 | 75.1 | 545.0 | 72.7 |

*Foot of response on the activation task.

Significant F values were obtained for the main effects of Condition, $F(1,16)=25.40$, $p<.001$ and Hemisphere, $F(1,16)=8.84$, $p<.05$. These results indicate that reaction time latencies were significantly longer during concurrent performance and that response latencies to right hemisphere presentations were shorter than to left hemisphere presentations. These significant main effects parallel those found in the numbers activation task condition where the Condition main effect was significant and the Hemisphere main effect approached significance.

Significant interactions were also found between Foot of response and Hemisphere, $F(1,16)=11.52$, $p<.01$ and among Foot of response, Condition ahd Hemisphere, $F(1,16)=12.74$, $p<.01$. These two interactions are shown in the bottom panels of Figure 3. Post hoc Newman-Keuls comparisons between the means of simple main effects in the first interaction revealed that subjects who used their right foot to respond to the activation task responded faster to right hemisphere presentations than left

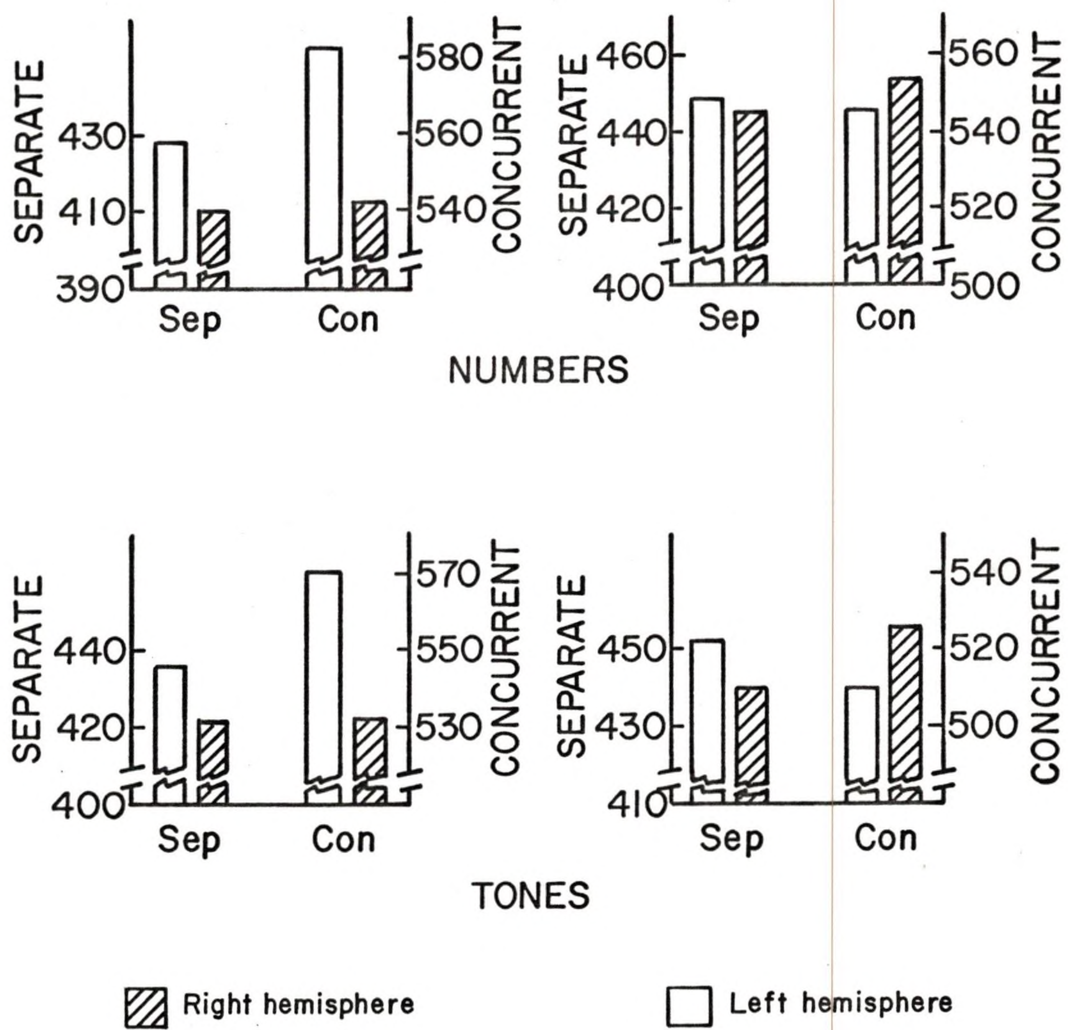


Fig. 3. Reaction time in msec in the numbers (above) and tones (below) activation tasks for subjects using their right foot (right panel and left foot (left panel) during separate (represented on the left ordinate) and concurrent (represented on the right ordinate) performance.

hemisphere presentations. There was no difference between right and left hemisphere presentations for subjects who used their left foot. Post hoc Newman-Keuls comparisons among the means of simple main effects in the second interaction revealed that subjects using their right foot to respond to the activation task took significantly longer to respond to left hemisphere presentations than right hemisphere presentations in the concurrent condition and even though they also tended to have significantly longer responses to left hemisphere than right hemisphere presentations in the separate condition, the differences in the concurrent condition were much larger. Subjects using their left foot tended to have significantly longer latencies to right hemisphere presentations in the concurrent condition and they tended to have significantly longer latencies to left hemisphere presentations in the separate conditions.

The data was analyzed for Order effects but since there were no significant main effects or interactions the results are only reported in Table 8 in the appendix.

Auditory Number (left-hemisphere) Activation Task Analysis. Performance on the number activation task alone and during concurrent performance with the criterion task was evaluated by means of a 2x2x2 repeated measures analysis of variance. The analysis had as independent variables the between subject effects of Sex, Foot of response and the within subjects effect of Condition. The means and standard deviations of this data are shown in Table 3. There appeared to be a large difference between the variances of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, $F$= 2.77, df= ,x, $p$

The results of the repeated measures ANOVA are summaried in Table 6 of the appendix. A significant F value was obtained for the Condition main effect, $F(1,15)=4.79$, $p<.05$ shows that subjects performed significantly better in the concurrent condition than in the separate condition.

TABLE 3

NUMBER OF CORRECT RESPONSES AND STANDARD DEVIATIONS FOR RIGHT AND LEFT HEMISPHERE ACTIVATION TASKS DURING SEPARATE AND CONCURRENT PERFORMANCE IN THE AUDITORY ACTIVATION TASK CONDITIONS

| | | Left Hemisphere | | | | Right Hemisphere | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Separate | | Concurrent | | Separate | | Concurrent | |
| Sex | Foot* | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD |
| Female | Right | 28.0 | 10.1 | 30.0 | 13.7 | 26.7 | 8.0 | 22.0 | 9.5 |
| Female | Left | 38.0 | 6.39 | 39.7 | 9.2 | 31.3 | 9.8 | 36.0 | 10.2 |
| Male | Right | 33.3 | 9.6 | 36.2 | 12.2 | 31.5 | 12.4 | 33.5 | 12.8 |
| Male | Left | 27.5 | 15.3 | 29.0 | 16.8 | 27.2 | 11.1 | 23.3 | 15.2 |

*Foot used to respond to the activation task.

The data was analyzed for order effects. Since there were no significant effects the results are only reported in Table 9 of the appendix.

Auditory Tones (right hemisphere) Activation Task Analysis. The performance on the tone activation task alone and during concurrent performance with the criterion task was evaluated by means of a 2x2x2 repeated measures analysis of variance identical to that performed for the numbers task. The means and standard deviations are shown in Table 3. There appeared to be a large difference between the variance of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, $F$= 2.56, df= , , $p$

The results of the repeated measures ANOVA are summarized in Table 10 of the appendix. No significant main effects were found. Significant interactions (shown in Figure 4) were found between Sex and Condition, $F(1,16)-6.11$, $p < .05$, and among Sex, Foot of response and Condition, $F(1,16)=13.52$, $p < .005$. Post hoc Newman Keuls analysis between the simple main effects revealed that females did significantly better during concurrent performance than when they performed the activation task alone. Their performance was enhanced more than male performance during concurrent performance. Neuman-Keuls analysis among the simple main effects of the second interaction revealed that females using their left foot did significantly better during concurrent performance than during separate performance but males using their left foot did significantly worse during concurrent performance than during separate performance.

The data was analyzed for Order effects. There was one significant effect, that of Sex, Order and Condition, $F(1,16)=10.21$, $p < .01$. Inspection of the means indicated that females did better when the tones task was first and males did better when the numbers task was first; in the concurrent condition, female performance was enhanced when the tone task was first while male performance declined when the tone task was first. The results are presented in Table 10 in the appendix.

## Summary of Results for the Auditory Activation Task Conditions

The data from these conditions do not support the predicted pattern of interference between the activation tasks and the criterion task.

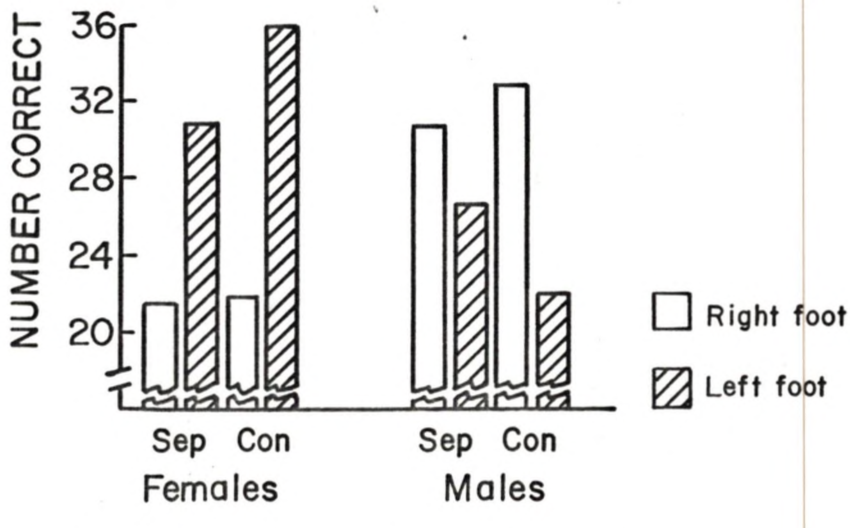


Fig. 4. Sex by Foot by Condition interaction in performance on the tones activation task (sep=separate; con=concurrent).

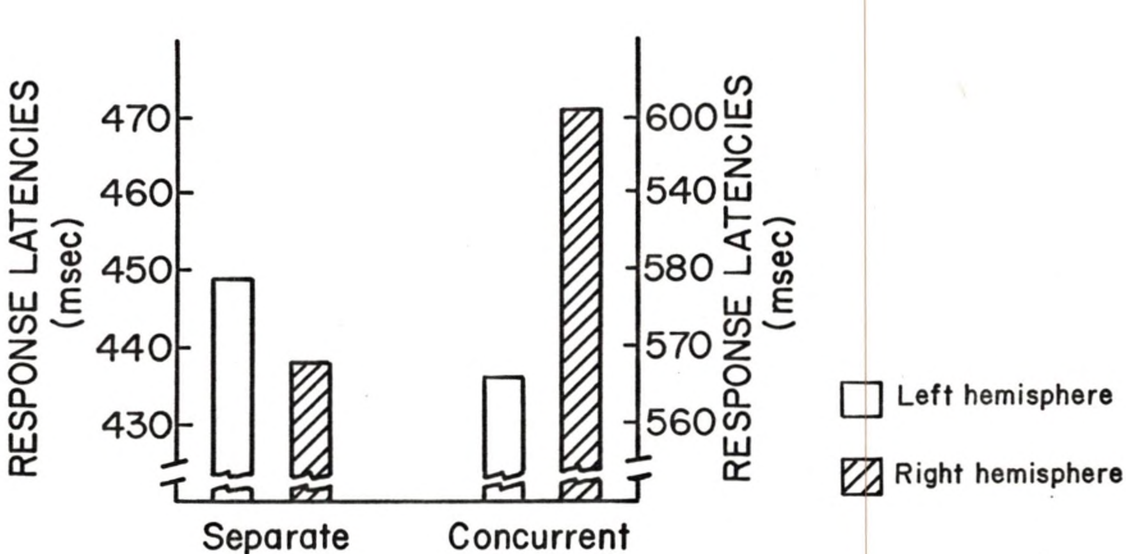


Fig. 5. Hemisphere by Condition interaction during the visual number activation task.

However, other patterns of interference appeared. The results of the analysis of the activation tasks taken together with the results of the analysis of the criterion task show that (1) concurrent performance always interferes significantly with performance on the criterion task and (2) concurrent performance enhances performance on the verbal activation task but does not enhance performance on the non-verbal activation task. The results of analyses of the criterion task during both activation tasks suggest that motor performance of the left foot interferes more with motor performance of the left hand and motor performance of the right foot interferes more with motor performance of the right hand (see Figure 3). Criterion task data during both conditions suggest that the motor performance of the right foot tends to interfere more than the motor performance of the left foot with hand performance. In addition, the results suggest that female performance on both tasks and male performance on the tones task differ according to which foot they use to respond to the activation task. Females tended to perform better on both auditory activation tasks and on the visual criterion task when they were using their left foot than when they were using their right foot to respond to the activation tasks. Conversely, the data suggest that males tended to perform better on both activation and criterion tasks when they were using their right foot than when they were using their left foot to respond to the auditory activation tasks. The effect was not as pronounced for males.

<u>Analysis of the Criterion Task during the Visual Number (left-hemisphere) Activation Task Condition</u>. The performance of the criterion task alone and during concurrent performance with the visual number activation task was evaluated by means of a 2x2x2x2 repeated measure analysis

of variance identical to that performed for the auditory number activation task. The means and standard deviations of this data are presented in Table 4. There appeared to be a large difference between the variances of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, $F$= 6.84, df= , , $p$=

TABLE 4

MEAN REACTION TIMES AND STANDARD DEVIATIONS FOR PRESENTATION TO RIGHT AND LEFT HEMISPHERES FOR SEPARATE AND CONCURRENT PERFORMANCE ON THE AUDITORY CRITERION TASK IN THE LEFT HEMISPHERE ACTIVATION TASK CONDITION

| | | Separate | | | | Concurrent | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Left | | Right | | Left | | Right | |
| Sex | Foot* | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD |
| Female | Right | 528.9 | 133.3 | 498.6 | 123.2 | 608.7 | 127.2 | 590.7 | 120.0 |
| Female | Left | 414.0 | 143.6 | 407.6 | 105.2 | 490.3 | 124.3 | 684.3 | 240.3 |
| Male | Right | 388.8 | 107.5 | 413.8 | 145.8 | 560.8 | 125.2 | 627.5 | 207.1 |
| Male | Left | 465.3 | 205.8 | 438.8 | 138.0 | 514.5 | 95.0 | 527.2 | 91.9 |

*Foot of response on the activation task.

The results of the repeated measures ANOVA are summarized in Table 11 in the appendix. The results do not support the hypothesis that the number task interferes relatively more with left hemisphere than right hemisphere performance of the criterion task during concurrent performance. In fact, the results support the opposite hypothesis. The Hemisphere x Condition interaction was significant, $F(1,18)=7.19$, $p < .05$. Neuman-Keuls comparisons between means of simple main effects in this interaction reveal that during concurrent performance with the activation task the right hemisphere had the greater decrement in performance (see Figure 5).

A significant F-value was also obtained for the Condition main effect, $F(1,18)=26.06$, $p<.001$). This expected result shows that the subjects' response latencies during concurrent performance were longer than their response latencies when performing the criterion task alone. In addition, a significant interaction (shown in Figure 6) was found among Sex, Foot of response and Condition, $F(1,18)=5.82$, $p<.05$. Post hoc Newman-Keuls comparisons between the means of simple main effects showed that females using their left foot to respond to the activation task experience a greater decrement in performance during the concurrent conditions than females using the right foot and males using their right foot experienced a greater decrement in performance during the concurrent conditions than males using their left foot.

An additional interaction was found between Sex, Foot of response, and Hemisphere, $F(1,18)=6.22$, $p<.05$ (shown in Figure 7). Post hoc Newman-Keuls comparisons between the means of simple main effects showed that males who used their right foot to respond to the activation task had significantly longer response latencies to right hemisphere presentations than to left hemisphere presentations. Furthermore, these males had a significantly greater difference between response latencies to right and left hemisphere presentations than either males who used their left foot or females who used their right foot. On the other hand, females who used their left foot to respond to the activation task had a significantly greater difference between responses to left and right hemisphere presentations.

The data was analyzed for Order effects. There were significant interactions among Foot of response, Order and Hemisphere; among Sex Order and Hemisphere and among Sex, Foot of response, Order and

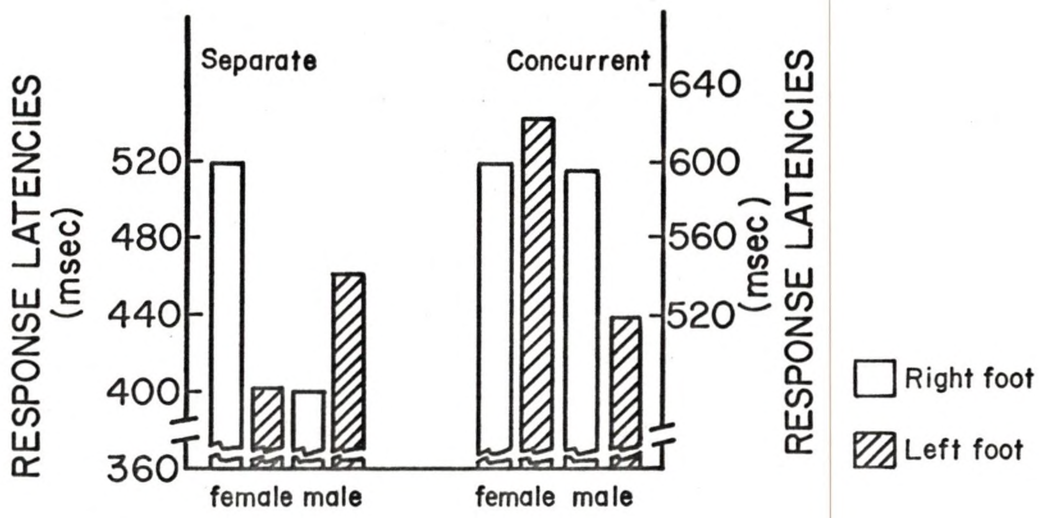


Fig. 6. Sex by Foot by Condition interaction during performance on the auditory criterion task during the visual number condition.

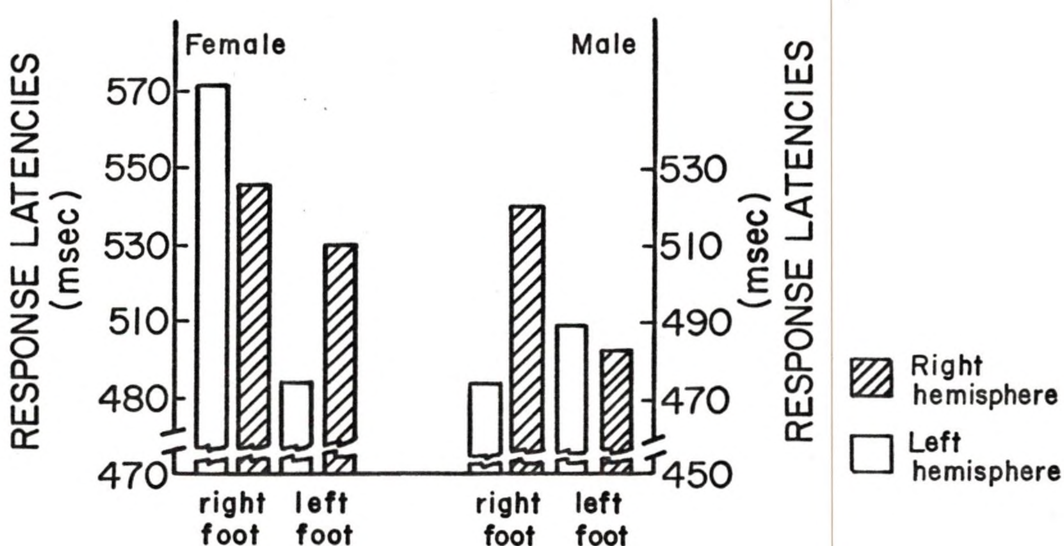


Fig. 7. Sex by Foot by Hemisphere interaction during performance on the auditory criterion task during the visual number condition.

Hemisphere. Inspection of the Foot of response, Order and Hemisphere interaction reveals that Order effects the response latencies to hemisphere probes. When the numbers task was first, the presentation to the left hemisphere-left foot response combination was the fastest, while the presentation to right-hemisphere-left foot response combination was the slowest; when the tones task was first, the presentation to the right hemisphere-left foot response was the fastest combination while the presentation to the right-hemisphere-right foot response was the slowest. In addition, inspection of the Sex, Order and Hemisphere interaction reveals that responses to the left hemisphere presentations were longer for females performing the numbers task first; responses to right hemisphere presentations were longer for females performing the numbers first but also worse for males performing the numbers second. Inspection of the Sex, Foot of response, Order and Hemisphere interaction revealed that responses to left hemisphere presentations differed from right hemisphere presentations in the following manner: going from separate to concurrent performance those subjects using their left foot had longer response latencies to left hemisphere presentations than those using their right foot in both orders; those subjects using their right foot had longer response latencies to right hemisphere presentations in the first order than in the second order.

Analysis of the Criterion Task during the Visual-spatial (right hemisphere) Activation Task Condition. The subject's performance on the validation task alone and during concurrent performance with the spatial activation task was evaluated by means of a 2x2x2x2 repeated measures analysis of variance identical to that performed for the numbers task. The means and standard deviations are shown in Table 5. There appeared to be a large difference between the variances of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, F= 5.18, df= , , p=

TABLE 5

MEAN REACTION TIMES AND STANDARD DEVIATIONS FOR PRESENTATION TO RIGHT AND LEFT HEMISPHERES FOR SEPARATE AND CONCURRENT PERFORMANCE ON THE AUDITORY CRITERION TASK IN THE RIGHT HEMISPHERE ACTIVATION TASK CONDITION

| | | Separate | | | | Concurrent | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Left | | Right | | Left | | Right | |
| Sex | Foot* | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD |
| Female | | 585.7 | 185.7 | 559.3 | 168.0 | 645.7 | 178.6 | 622.3 | 201.4 |
| Female | | 399.6 | 102.3 | 407.3 | 88.5 | 553.9 | 116.2 | 564.4 | 135.8 |
| Male | | 388.0 | 154.2 | 410.7 | 142.7 | 536.7 | 133.0 | 544.8 | 158.3 |
| Male | | 371.6 | 116.9 | 369.6 | 118.8 | 508.6 | 174.4 | 513.0 | 181.2 |

*Foot of response on the activation task.

The results of the repeated measures ANOVA are summarized in Table 12 in the appendix. The results of this analysis do not support the hypothesis that the spatial task interferes relatively more with right hemisphere than left hemisphere performance on the criterion task during concurrent performance. A significant F-value was obtained for the Condition main effect, $F(1,16)=27.51$, $p<.001$. This expected result indicates that reaction time latencies were significantly longer during concurrent performance than during separate performance. There were no significant interactions.

The data was analyzed for Order effects but no significant effects were found. The results are only reported in Table 12 of the appendix.

Visual Number (left hemisphere) Activation Task Analysis. Performance on the number activation task alone and during concurrent performance with the criterion task was evaluated by means of a 2x2x2 repeated measures analysis of variance identical to that in the auditory number activation task analysis. The means and standard deviations are shown in Table 6. There appeared to be a large difference between the variances of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, F= 3.91, df= , , p=

TABLE 6

NUMBER OF CORRECT RESPONSES AND STANDARD DEVIATIONS FOR RIGHT AND LEFT HEMISPHERE ACTIVATION TASKS DURING SEPARATE AND CONCURRENT PERFORMANCE IN THE VISUAL ACTIVATION TASK CONDITIONS

| | | Left Hemisphere | | | | Right Hemisphere | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Separate | | Concurrent | | Separate | | Concurrent | |
| Sex | Foot* | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD |
| Female | Right | 39.3 | 6.0 | 45.9 | 4.5 | 47.5 | 5.5 | 48.0 | 4.1 |
| Female | Left | 27.0 | 8.9 | 39.0 | 8.7 | 37.8 | 10.9 | 36.2 | 13.0 |
| Male | Right | 41.2 | 5.5 | 41.3 | 5.7 | 43.2 | 12.6 | 41.2 | 11.7 |
| Male | Left | 40.3 | 8.0 | 42.7 | 5.1 | 46.7 | 7.6 | 45.5 | 7.2 |

*Foot used to respond to the activation task.

The results of this analysis are summarized in Table 13 in the appendix. A significant F-value was obtained for the Condition main effect, $F(1,16)=4.51$, $p<.05$. This result indicates that subjects performed significantly better on the task during concurrent performance with the criterion task.

Visual-spatial (right hemisphere) Activation Task Analysis. The performance on the visual-spatial activation task alone and during concurrent performance with the criterion task was evaluated by means of a 2x2x2 repeated measures analysis of variance identical to that performed on the other activation tasks. The means and standard deviations of the data are shown in Table 6. There appeared to be a large difference between the variances of the treatment groups. Thus, a Hartley $F_{(max)}$ test was performed to test for homogeneity of variance. The differences were not significant, $F = 10.05$, df= , , $p =$

The results of the repeated measures ANOVA are summarized in Table 14 in the appendix. No significant main effects were found.

The data was analyzed for Order effects but since there were no significant main effects nor interactions, the results are only presented in Table 14 in the appendix.

## Summary of Results for the Visual Activation Task Conditions

The data from these conditions do not support the predicted pattern of interference between the activation tasks and the criterion task. However, as in the auditory activation task conditions, other patterns occur. The results of the analysis of the activation tasks taken together with the results of the analysis of the criterion task indicates that (1) concurrent performance always interferes with performance on the criterion task and (2) concurrent performance enhances performance on the verbal task but interferes with performance on the nonverbal task. In addition, the results suggest that the effect of performing verbal activation task simultaneously with the criterion task differed between females and males according to the foot they used to respond to the activation task. That is, it was found that males using their right foot to respond to the verbal activation task had significantly longer response latencies to the right hemisphere tones than to the left hemisphere tones; neither males using their left foot to respond to the activation task nor females using their right foot to respond to the activation task demonstrated hemisphere differences in response latencies. Also using the right foot interfered more with male performance on the criterion task and using the left foot interfered more with female performance on the criterion task during concurrent performance.

## Overall Summary of Results

Overall, the data appear not to support the major hypothesis that the verbal activation tasks interfere relatively more with left hemisphere than right hemisphere performance on the criterion task and the non-verbal tasks interfere relatively more with right hemisphere than left hemisphere performance on the criterion task. However, other patterns of interference occurred between the criterion and activation tasks. First, all activation tasks interfered significantly with the responses to both right and left hemisphere presentations in the respective criterion tasks. Second, performance on both verbal activation tasks was significantly enhanced during concurrent performance with the respective criterion task while the performance on the non-verbal activation tasks tended to be interfered with by the respective criterion tasks. Third, using the right foot to respond to the activation task interferes more with right hand (left hemisphere) performance and using the left foot interferes more with left hand (right hemisphere) performance. Fourth, using the right foot to respond to the auditory activation task tends to result in a greater decrement in overall criterion (task) performance than using the left foot in the auditory activation task conditions. This pattern also holds for males in the visual numbers activation task condition but is the opposite for females. Finally, the sex of the subject contributes in a complex way to the pattern of interference between the criterion task and activation task especially in the visual activation task condition.

Caution must be used in interpreting the results of this study. The condition effect was significant in six out of eight analyses and thus likely a reliable finding. Of the remaining 154 statistical tests 14 were significant. With an  level of .05 one would expect eight of these tests to be significant by chance alone.

## CHAPTER IV

## DISCUSSION

The primary purpose of the present research was to investigate the concurrent task procedure as an alternative method of studying brain lateralization of higher functions in the neurally intact individual. This procedure, in which the subject attempts to perform two tasks simultaneously, was originally developed for studying processing demands of cognitive tasks over time (Posner and Boies 1971, Posner and Klein 1973). In these studies, concurrent task procedure was conceptualized in terms of a limited capacity model of the human brain (Kahneman 1973). In employing this procedure in this study, it was assumed that the brain has two channels of processing (i.e., that each hemisphere constitutes a separate channel of processing) and even though these channels are constrained by a certain overall processing capacity when they function together, they are still capable of processing more together than either one can process separately. If each hemisphere has a limited and separate processing capacity, then it follows that interference between two tasks that require processing within the same hemisphere would be greater than the interference between two tasks that could be divided between the hemispheres (i.e., one task in each hemisphere).

The primary hypothesis in the present research, based on the theoretical model presented above, was related to the processing demands associated with each of four activation tasks. It was expected that the processing required in each of the putatively lateralized activation tasks would interfere selectively with that portion of the criterion task which was processed by the same hemisphere. In other words, it was expected that the verbal activation tasks would interfere more with the left hemisphere than right hemisphere performance on the criterion task and the non-verbal activation tasks would interfere more with right than left hemisphere performance on the criterion task. An easily interpreted pattern of interference between activation task and criterion task was not found. The results suggested that the processing demands of these tasks were not divided between the hemispheres according to the current theoretical model of lateralized brain functioning. In the auditory activation task conditions, the response latencies to right hemsiphere presentations tended to be shorter during dual performance with both verbal and non-verbal activation tasks. In the visual activation task conditions, the only result that applied to the hypothesis was significant in the opposite direction than predicted. Moreover, the results appeared to vary according to the sex of the subject, the foot used to respond to the activation task, and the input modality of the task. Although the primary hypothesis was not confirmed this research provided some evidence that the concurrent task procedure would be useful in investigating brain lateralization once more information about how factors such as the sex of the subject, input modality and nature of the motor responses determine the pathways of subprocesses the subject employs in processing information and responding to the task.

Before an attempt can be made to interpret the pattern of interference obtained in this study, i.e., the difference between performance on the criterion task alone and concurrently with the activation task, it is necessary to interpret the data obtained during the subject's performance on each criterion task alone. This is accomplished by analyzing how individual performances differed according to the sex of the subject and the sensory (input) modality of the task. The behavioral differences suggest that the organization of perceptual-motor pathways within the brain varies according to the sex of the subject and input modality. This variance is incompatible with the directness of path model which asserts that perceptual and response pathways will be integrated within the same hemisphere if the input is directed to the same hemisphere that controls the motor response. The second part of this discussion is concerned with how this postulated variance in perceptual-motor pathways (subprocesses) might account for the pattern of interference found between the foot used to respond to the activation task and the subject's motor responses to perceptual stimuli in the concurrent condition. It was also clear from the pattern of interference in the visual activation task condition that sex is a significant source of variance during concurrent performance. While the difference in behavior is clear the internal mechanisms producing the difference are not. The behavioral difference suggests that perceptual motor pathways during concurrent performance differed between female subjects depending upon the foot of response.

The question of verbal vs non-verbal task interference with each criterion task is considered in light of the findings that the processing of the reaction time probe may not be integrated within one hemisphere. It is apparent that even with this different organization of processing, the primary hypothesis that verbal tasks would interfere more with the left hemisphere component of a task and the non-verbal tasks would interfere more with the right does not adequately account for the pattern of interference obtained in this study. Some of the deviations appear to be results of hemisphere rivalry (Kinsbourne 1970). Finally, implications for future research will be examined.

Perceptual-Motor Pathways (subprocesses) as inferred from Simple Reaction Time to Lateralized Light Flashes. It has been assumed in this study that in the case where an ipsilateral response to lateralized light is required there would be no difference between right and left hand reaction time (Filbey and Gazzaniga 1969, Moscovitch and Catlin 1970). No difference was found for female subjects, implying that females may integrate the stimulus and response within the same hemisphere.

Males, however, tended to have a left visual half-field superiority. Data (Anzola, Bertoloni, Buchtel, & Rizzolatti 1977, Jasper and Raney 1939, and Jeeves & Dixon 1970) obtained from research designs using both hands, either to respond simultaneously to lateralized light flashes or to respond after making a choice between the hands suggests that hand or visual half-field superiority may depend upon the nature of the response and on the sex of the subject. These researchers found a left visual half-field superiority in response tasks similar to the task employed in the present study. These studies used only male subjects. These findings suggest that integration of stimulus and response pathways within the same hemisphere may not be the only organization of subprocesses available to the male subject; males may integrate the two visual half-fields within the right hemisphere to determine the location of stimuli in space.

Another difference between males and females during separate performance on the visual criterion task condition was that males tended to take longer with both hands than females took with either hand.

In past research, when slightly but systematically slower response times were found after changing the nature of the response task this slower response latency was attributed to the greater complexity of the second response task (Smith 1968). For example, bilateral responses have been found to be slightly but systematically slower than corresponding unilateral responses (Jeeves 1969, Jeeves and Dixon 1970, Nakamura and Saito 1974). In particular, DiStefano, Morelli, Marzi, and Berlucci (1980) attributed the longer response latencies during bilateral responding they found to the increased time demands necessary to organize a more complex task. Specifically, they argued that bilateral task required the engagement of a bilaterally distributed motor control (subprocess). The difference in response time between unilateral and bilateral control was attributed to inter-limb competition effects in more complex types of motor tasks such as those found when the same mechanism controls both limbs (bilateral control). A number of studies on subjects with brain lesions suggest the existence of a mechanism that can control bilateral motor responses of both hands and locate this mechanism in the left hemisphere (Gazzaniga et al. 1967, Wyke 1971, and Zaidel and Sperry 1977). Thus, longer male response latencies suggest that males might use a bilateral motor control mechanism located in the left hemisphere for responding while the shorter response latencies in females suggest that females might use a stimulus-response mechanism located in each hemisphere for responding.

In summary, female unilateral right and left hand response latencies to single randomly presented lateralized light flashes with the ipsilateral hand did not differ; this data suggests that females tend to integrate the visual stimulus and hand response within a single hemisphere. Conversely, males tended to take longer with both hands than the females did with either hand and to respond to the lateralized light flashes faster with the left hand. While this behavioral difference is clear, the internal mechanisms producing this difference are not. However certain speculations can be made. First with respect to the longer male responses, this longer response time suggests that males tend to employ a bilateral motor control mechanism in this particular task. With respect to the left visual field superiority, it might be argued that males tend to combine two subprocesses; they may tend to process the light flash from either half-field within the right hemisphere and control the motor responses of either hand in the left hemisphere. Thus, the different patterns of response latencies between right and left hand responses in males and females suggest differences in the organization of subprocessing stages in simple perceptual-motor tasks. Smith (1978) has postulated just such a multiple stage model to explain differences between "choice reaction time" when the task requirements are changed. In addition, the more complex organization of males in this task is supported by the research which shows that males are more lateralized and better at complex visual-spatial tasks than females (see Harris 1978 for a review of sex differences in spatial ability).

Perceptual-Motor Pathways as Inferred from Simple Reaction Time to Lateralized Sound Stimuli. It has been assumed in this study that there would be no difference between presentations to the right and left hemispheres when ipsilateral responses to lateralized sounds are required (Murphy and Venables 1970). In the present study this assumption was confirmed. The results might be interpreted to indicate that both females and males integrate the auditory stimulus and motor response pathways within a single hemisphere. Females, however, tended to have longer response latencies than males. Some speculations may be made about this longer response latency. It may indicate a tendency toward a more complex organization of auditory stimuli in females like that postulated for visual stimuli in males. Researchers have found that more complex auditory tasks do require longer response latencies. Bertera, Callan, Parsons and Pishkin (1975) found that bilateral response latencies to lateralized tones were systematically longer than corresponding unilateral responses and Peters (1980) found longer unilateral response latencies with both hands on a more complex task. These results taken together with other findings (Callan, Klisz, & Parsons 1974, and Kimura 1967) that males responded faster to lateralized tones with the ipsilateral hand and the present results suggest that females may tend to use a more complexly organized response to tones.

The question of whether females integrate the tone stimuli from both ears within the left or right hemisphere cannot be answered because each ear has both contralateral and ipsilateral connections to each hemisphere. Because of multiple neural pathways, a delay while stimulus information is transferred to the opposite hemisphere is not necessary for integration of sounds from both ears within a single hemisphere. Some data obtained from research using the same task as employed in the present research provides evidence for a hand or ear superiority in the female. For example, Dick, Rosen and Karp (1977) found that tones in the right ear were responded to faster than tones to the left ear. In addition, Peters (1980) found a right ear preference in a more complex task. This data suggests that females may tend to integrate information from both ears within the left hemisphere.

In summary, the different length of response latencies between males and females is tentatively attributed to differences in organization of the perceptual-motor pathways. One organization of subprocessing that might tend to produce the male pattern of shorter response latencies is the integration of stimuli and motor responses within the same hemisphere. While the female pattern of longer response latencies might be the result of analyzing information from both ears in the same hemisphere to locate sound. This location information might be relayed to an area in the left hemisphere where a bilateral motor control system coordinates hand response.

Perceptual-Motor Pathways (subprocesses) as Inferred from the Pattern of Interference Between the Foot of Response on the Activation Task and Reaction Time to Lateralized Stimuli. In the present research it was found that foot responses interfered more with ipsilateral hand responses than contralateral hand responses in the auditory activation condition during concurrent performance. This pattern was found in both verbal and non-verbal conditions. In other words, those subjects using their right foot to respond to the activation task had a greater decrement in the response latency to left hemisphere presentations and those using their left foot to respond to the activation task had a greater increase in the response latency to right hemisphere presentations. In addition to this lateralized interference, there tended to be a greater decrement in overall performance on the criterion task in those males who used their right foot to respond to the activation task.

This pattern of interference has been found by other researchers. Along with other findings, Kinsbourne (1973) found that ipsilateral foot movement interfered with hand movement more than contralateral foot movement. This find led Kinsbourne (Kinsbourne & Cook, 1978) to postulate a model of cerebral functional space:

> The functional distance between any two cerebral control centers decreases with the extent to which they collaborate on concordant tasks and with the extent to which they compete on discordant tasks. Thus, if effector A can be paired with either effector B (functionally close) or effector C (functionally distant), then the AB combination will more efficiently perform concordant movement sequences, whereas the AC combination will more effectively perform discordant movement sequences (p. 267).

Both patterns of interference found in the present research could be accounted for by the cerebral functional space model given the previously suggested perceptual-motor pathways used by males and females in processing lateralized light flashes. If the male tends to use a bilateral motor control mechanism located in the left hemisphere during the visual criterion task then the right foot responses would interfere with both hands more than the left foot responses would interfere with either hand. If the female uses unilateral motor control integrated within each of the cerebral hemispheres with the corresponding perceptual stimuli, her foot response would interfere more with the ipsilateral hand response.

The pattern of interference found above does not appear in the interference between the visual activation task and the auditory criterion task with the exception of male subjects who used their right foot. They had significantly slower response with both hands. It is apparent from these data that the modality of input also influences the pattern of interference between tasks; the pattern of interference differed between the auditory and the visual modalities even though the tasks in both conditions were designed to be as analogous as possible. Interference between the motor components was a significant source of variance in the auditory activation task condition while the sex of the subject was a significant source of variance in the visual activation task condition.

<u>Sex Differences in the Patterns of Interference</u>. In this study, the pattern of interference between the visual verbal activation task and the criterion task differed according to the sex of the subject. Specifically male subjects who used their right foot had significantly longer response latencies with both hands during concurrent performance with the verbal activation task while female subjects who used their left foot in this task had significantly longer response latencies with both hands.

Sex differences suggested by previous research appears to be complex and contradictory (Fairweather 1976). In essence three major hypotheses have been proposed to explain differences in laterality between males and females: (1) males are more lateralized and better at visual-spatial processing and females are better at verbal processing (see Harris 1978 and Macoby and Jacklin 1975 for reviews of the literature supporting this hypotheses), (2) males are more lateralized than females (Lansdell 1962, Lake and Bryden 1976, McGlone and Davidson 1973, McGlone and Kertsz 1974, Hannay 1976, and Hannay and Malone 1976), and (3) males and females differ in processing strategies (Metzger and Antes 1976). None of these hypotheses by themselves can explain why significant sex differences do not appear in the pattern of interference between tasks in the auditory activation task condition but do appear in the visual activation task condition.

While the behavioral differences between males and females is clear the internal mechanisms producing this difference is not. However certain speculations can be made. If it is postulated that certain function space is the major factor in determining interference between tasks, then the data suggests that the auditory criterion task was organized differently by males and females during concurrent performance with the verbal activation task. The pattern of interference found suggests that male hand responses are coordinated within the left hemisphere and female hand responses are coordinated within the right hemisphere during the concurrent condition (i.e., using the right foot interferes with male hand performance than using the left foot and using the left foot interferes more with female hand performance than using the right foot).

These results might be interpreted to mean that males are more lateralized than females. In other words, males appear to coordinate both hands only with the left hemisphere suggesting that this processing mechanism is probably not duplicated in the right hemisphere. Therefore, it appears that both processing of the verbal activation task and processing of the criterion task must take place in the left hemisphere. Females appear to have duplicate processing mechanisms in both hemispheres. It appears that they shift processing of the criterion task to the right hemisphere while they are processing the verbal activation task in the left hemisphere. This ability to shift coordination of hand movement to the right hemisphere would also explain why the apparent right hemisphere neglect of left side perceptual motor processes in left space found in male performance does not appear in female auditory criterion task performance during concurrent performance with the verbal activation task. This hemispheric neglect which suggests Kinsbourne's (1973) theory of hemisphere rivalry will be explained in greater detail later.

Hemispheric Control of Verbal and Non-Verbal Processing as Inferred from the Pattern of Interference Between Activation and Criterion Tasks. Previous research has shown that verbal tasks require more left hemisphere processing and non-verbal tasks require more right hemisphere processing. In the present research, it was hypothesized that the verbal task would interfere more with right hand than left hand performance on the criterion task during concurrent performance and the non-verbal task would interfere more with left hand than right hand performance on the criterion task during concurrent performance. This hypothesis was not confirmed by the results of the study.

The overall pattern of the data suggests that verbal and non-verbal tasks create essentially the same pattern of interference with the criterion task within subjects (see Tables 1, 2, 4 & 5). For example, if the right hand is faster than the left during concurrent performance with the verbal task than it is faster during concurrent performance with the non-verbal task. However, a different pattern of interference was shown across modality, sex, and foot of response. The differences may be a result of the fact that these variables are between subject variables; the between variables might be a greater source of variance than the within subject variable of the task. This fact suggests that groups of subjects which are identical on between subject variables might be examined individually. Therefore, the data was divided into eight groups that were identical on between subject variables. The right and left hand performances are evaluated separately because the data will not be controlled for the differential effects of between variables on the right and left hand when hand performances in these groups are analyzed.

To compare the effect of verbal and non-verbal tasks on hand performance, the primary hypotheses must be expressed as the alternative hypotheses that the verbal task will interfere more than the non-verbal with the right hand performance and the non-verbal task will interfere more than the verbal task with left hand performance. When interference between the verbal task and the right hand performance on the criterion task (both tasks are processed by the same hemisphere) is compared to the interference between the non-verbal task and right hand performance on the criterion task (each task is processed by a different hemisphere), the verbal task is found to interfere more in six of these eight groups. Conversely, when interference between the verbal task and the left hand performance is compared to the interference between the non-verbal task and left hand performance on the criterion task, the interference between the non-verbal task and left hand is only greater in two of the eight groups.

In analyzing right hand response latencies, it is found that both of the groups with longer right response latencies for the non-verbal tasks than verbal tasks are males in the visual activation task condition. The explanation for this result is not evident.

In analyzing the left hand response latencies, it is found that four of the eight groups have very slow left hand responses during the verbal activation task. Two of these groups (females using their right foot in the auditory activation task and males using their right foot in the visual activation task) are similar. Taking into account the previously developed hypothetical processing pathways, it is found that in both cases most of the processing is assumed to be mediated by the left hemisphere. That is, the verbal task, the foot response, and the right hand response to the right stimulus half-field are all being mediated by the left hemisphere. Only the perception of stimuli in the left perceptual field and the ipsilateral hand response is being mediated by the right hemisphere. This decrement in the left hand performance suggests an induced unilateral neglect of the left side of the body. Kinsbourne (1970) argues that when "one hemisphere is overactive, or the other depressed, imbalance results, so that stimuli will be more readily observed if they are so placed as to elicit orientation in the direction controlled by the preponderant hemisphere" (page 133). Moreover, with more than one stimulus, attention is preempted by the stimulus most contralateral to the preponderant hemisphere, the rest being ignored. A review of the literature (Weinstein 1977) shows unilateral neglect usually occurs on the left side of the body in subjects with lesions in the right hemisphere. Thus, it is speculated that the pattern of interference between dual tasks might depend upon the relative activation of each hemisphere during performance. The explanation of the results for the left hand is not evident.

Other factors which appear to affect the pattern of interference between the criterion task and the activation task must also be taken into account when interpreting the data. One of these factors is the relative verbal nature of the activation task. Performance on the verbal activation task improved during concurrent performance and performance on the non-verbal declined. This data suggests that the verbal task was more protected from interference from a perceptual-motor task than the non-verbal tasks. Research shows protection of verbal (primary) tasks during dual performance with perceptual-motor (secondary) tasks (Kerr 1973). In this study, this effect seems to result in an accuracy-speed trade off. In the verbal concurrent condition, the subject's performance on the activation task became more accurate while his/her performance on the criterion task was less efficient than concurrent performance on the criterion in the non-verbal condition. In the non-verbal condition, the subject's performance on the activation became less accurate while their performance on the criterion task was more efficient than during concurrent performance in the verbal condition. This difference does not appear to depend upon the difficulty of the task (as measured by performance) because one non-verbal task was more difficult and one less difficult than the corresponding verbal task. McFarland and Ashton (1979) and Bowers et al. (1980) also found that difficulty (as rated by the subject) was not related to the pattern of interference. In particular, the difference between verbal and non-verbal task interference with a secondary task was not related to difficulty of the task. The pattern of interference between concurrent tasks appears to depend upon the relative amount of verbal processing required by both tasks.

## Implications for Research

The results of this study have implications for research methodologies measuring attention and laterality within the neurally intact subject. In general, research methodologies investigating either attention or laterality require a more complex model of brain subprocessing.

In particular, investigators using concurrent task procedures may need to reevaluate their findings. One researcher, McLeod (1978) has found that different types of responses in the secondary task produce different patterns of interference with the same primary task. However, he did not propose lateralization of processing as a possible explanation of this inconsistency between response types. Other researchers have also arrived at the conclusion that concurrent task methodology requires a more complex model of brain subprocesses. Ogden, Martin and Paap (1980) argue that "until it is known what strategies are available to a subject in a dual-task experiment, it will be difficult to use secondary task performance to evaluate the attentional demands of a primary task" (p. 366).

The present research points to some of the factors influencing allocation of attention in secondary tasks: (1) More complex secondary tasks may require different subprocessing mechanism rather than the simple addition of a decision making mechanism (deeper processing) to the simple reaction subprocesses (Smith 1968). This alternative subprocess may differ according to the sex of the subject. (2) When more than one response is required of the subject, such as in performing concurrent tasks where one response is required for each task, the data suggests that cerebral functional space must be taken into account. (3) The relative activation of the hemispheres may influence attention. A more active left hemisphere might impose an inhibitory influence on the right hemisphere when it is overloaded. (4) Verbal tasks may interfere more with secondary tasks than non-verbal tasks; the data suggests that verbal tasks appeared to be more protected and performance on verbal tasks may even improve during concurrent performance.

In addition, the models of the brain functioning employed in attention research assume one channel of information processing. The present research suggests a hierarchy of multiple channels, each level constrained by the processing capacity of a higher-order channel. While these interpretations are tentative, the data is suggestive. Further research designed to investigate the possibility of multiple channels of processing within the brain is proposed.

Laterality research presents the researcher with an array of complex, contradictory, and paradoxical findings. The present research suggests that this area of research needs a more complex model of the basic subprocess within the brain before conclusions can be drawn about the more complexly organized processes. More specifically, behavioral differences found in the present research suggests that the basic structure of internal mechanisms differ according to the sex of the subject, the modality of the task, and other processing taking place at the same time.

In addition, the data suggests that processing in both hemispheres depends upon the relative amount of processing taking place within each hemisphere as well as the specific processing taking place. Thus, it appears that mutual interference and attentional bias are independent dimensions of brain functioning. If these are independent dimensions of brain functions, it follows that there are two types of attention operating within the brain. While these interpretations are tentative, the data suggests that further investigation is necessary to delineate a model of brain functioning that would take into account the sex of the subject, the modality of the task, the relative activation of the hemispheres. In particular, research designed to investigate the possibility of two independent sources of attention is proposed.

# APPENDICES

# APPENDIX A

# INSTRUCTIONS AND PROCEDURES FOR OTHER ACTIVATION TASK CONDITIONS

Instructions for Auditory Right Hemisphere Activation Task Condition

Instruction in the task was begun by telling the subject "you will hear a random series of ten tones at intervals of two seconds via these earphones. Listen for increasing or decreasing sequences of three tones. In other words, when any three successive tones form a sequence of increasing or decreasing frequencies, press the foot pedal before the next tone. After you respond--that is, after a sequence of three increasing or decreasing tones--start searching for a new series. You are not to respond to overlapping sets."

The rest of the procedure and instructions in this condition is the same as for the auditory left hemisphere activation portion of the study.

Instructions for Visual Left Hemisphere
Activation Task Condition

Instruction in the task was begun by telling the subject "you will see a random series of numbers between 0 and 9 at intervals of two seconds on this memory drum. Watch for increasing or decreasing sequences of three numbers. In other words, when any three successive numbers for a sequence of increasing or decreasing values, press the foot pedal before the next number. After you respond--that is, after a sequence of three increasing or decreasing numbers--start searching for a new series. You are not to respond to overlapping sets. For example, if you see the numbers 1,2,5,6,3,7,9 you should respond only after the 5 and the 9."

After the instructions were given, the subject was administered the first practice set of the activation task which was two minutes in duration with numbers presented every two seconds. After a 30 second rest interval the subject was administered the second practice set which was three minutes in duration with numbers presented every second. Next performance on the activation task after practice was measured. The baseline set was four and one half minutes in duration and was presented at a rate of one number per second. If the subject did not reach the criterion of 50% accuracy, he/she was released from the experiment at this point.

Immediately following completion of this portion of the experiment the subject was introduced to the auditory criterion task. He/she was instructed as follows: "You will hear a tone in one ear via these earphones. When you hear the tone press the switch on the same side with the hand on the same side. The tones will sound in a random right-left sequence at variable time intervals averaging eight seconds. Press the key as quickly as you can. The set will last four minutes. Next the subject responded to tones for six minutes and his/her responses were recorded. The first 10 reaction times were discarded from the analysis.

The rest of the procedure and instructions follow that given for the auditory left hemisphere activation task.

Visual Right Hemisphere Activation Task Condition

Instruction in this task was begun by telling the subject "you will see a random series of squares in these ten positions on the memory drum. Watch for any series of 3 squares which shifts to the right or the left. In other words, when any three successive squares shift to the right or to the left press the foot pedal before the next square. After you respond--that is after a sequence of three squares to the right or to the left--start searching for a new series. You are not to respond to overlapping sets.

After the instructions were given the subject was administered the first practice set of the activation task which was two minutes in duration with squares presented every two seconds. After a 30 second rest interval the subject was administered the second practice set which was three minutes in duration with numbers presented every second. Next performance on the activation task after practice was measured. This baseline set was four and one half minutes in duration and was presented at a rate of one number per second. If the subject did not reach the criterion of 50% accuracy, he/she was released from the experiment at this point.

Immediately following completion of this portion of the experiment the subject was introduced to the criterion task. He/she was instructed as follows: "You will hear a tone in one ear via these earphones. When you hear the tone press the switch on the same side with your hand. The tones will sound in a random right-left sequence at variable time intervals averaging eight seconds. Press the key as quickly as you can. The set will last four minutes. Next the subject responded to tones for six minutes and his/her responses were recorded. The first 10 reaction times were discarded from the analysis.

The rest of the procedure and instructions follow that given for the auditory left hemisphere activation task.

# APPENDIX B

## ANOVA SUMMARIES FOR CRITERION ACTIVATION TASKS

TABLE 7

ANOVA SUMMARY FOR VISUAL CRITERION TASK
LEFT HEMISPHERE CONDITION

| Source | df | Mean Square | F-Test |
|---|---|---|---|
| Sex (S) | 1 | 19751.68 | 1.25 |
| Foot (F) | 1 | 1169.04 | 0.07 |
| Ord (0) | 1 | 13324.60 | 0.84 |
| S x F | 1 | 92318.13 | 5.82* |
| S x 0 | 1 | 138548.19 | 8.74** |
| F x 0 | 1 | 10521.09 | 0.66 |
| S x F x 0 | 1 | 6321.27 | 0.40 |
| Error (between) | 16 | 15850.64 | |
| Cond (C) | 1 | 367164.81 | 53.82*** |
| S x C | 1 | 6885.19 | 1.01 |
| F x C | 1 | 9740.54 | 1.43 |
| 0 x C | 1 | 15733.86 | 2.31 |
| S x F x C | 1 | 2025.87 | 0.30 |
| S x 0 x C | 1 | 40302.93 | 5.91* |
| F x 0 x C | 1 | 297.51 | 0.04 |
| S x F x 0 x C | 1 | 4468.99 | 0.66 |
| Error | 16 | 6822.03 | |
| Hemisphere (H) | 1 | 4468.96 | 3.36 |
| S x H | 1 | 2175.53 | 1.63 |
| F x H | 1 | 6032.57 | 4.53* |
| 0 x H | 1 | 943.77 | 0.71 |
| S x F x H | 1 | 2350.31 | 1.77 |
| S x 0 x H | 1 | 36.26 | 0.03 |
| F x 0 x H | 1 | 635.51 | 0.48 |
| S x F x 0 x H | 1 | 341.28 | 0.26 |
| Error | 16 | 1331.32 | |
| C x H | 1 | 162.76 | 0.16 |
| S x C x H | 1 | 162.77 | 0.16 |
| F x C x H | 1 | 1592.53 | 1.57 |
| 0 x C x H | 1 | 256.76 | 0.25 |
| S x F x C x H | 1 | 2784.26 | 2.74 |
| S x 0 x C x H | 1 | 178.76 | 0.18 |
| F x 0 x C x H | 1 | 372.10 | 0.37 |
| S x F x 0 x C x H | 1 | 2007.48 | 1.98 |
| Error | 16 | 1014.74 | |
| Total | 95 | 12140.77 | |

*p <.05
**p <.01
***p <.001

TABLE 8

ANOVA SUMMARY FOR VISUAL CRITERION TASK
RIGHT HEMISPHERE CONDITION

| Source | df | Mean Square | F-Test |
|---|---|---|---|
| Sex (S) | 1 | 25675.92 | 0.99 |
| Foot (F) | 1 | 1617.01 | 0.06 |
| Ord (O) | 1 | 570.38 | 0.02 |
| S x F | 1 | 41334.25 | 1.59 |
| S x O | 1 | 37446.00 | 1.44 |
| F x O | 1 | 2128.20 | 0.08 |
| S x F x O | 1 | 30.37 | 0.00 |
| Error (between) | 16 | 25971.67 | |
| Cond (C) | 1 | 228345.44 | 25.40*** |
| S x C | 1 | 18040.27 | 2.01 |
| F x C | 1 | 15000.00 | 1.67 |
| O x C | 1 | 20886.17 | 2.32 |
| S x F x C | 1 | 4676.02 | 0.52 |
| S x O x C | 1 | 8029.95 | 0.89 |
| F x O x C | 1 | 10880.06 | 1.21 |
| S x F x O x C | 1 | 9760.65 | 1.09 |
| Error | 16 | 8990.36 | |
| Hemisphere (H) | 1 | 3850.72 | 8.84** |
| S x H | 1 | 737.03 | 1.69 |
| F x H | 1 | 5017.07 | 11.52** |
| O x H | 1 | 26.05 | 0.06 |
| S x F x H | 1 | 433.50 | 1.00 |
| S x O x H | 1 | 600.02 | 1.38 |
| F x O x H | 1 | 149.99 | 0.34 |
| S x F x O x H | 1 | 155.04 | 0.36 |
| Error | 16 | 435.51 | |
| C x H | 1 | 40.04 | 0.13 |
| S x C x H | 1 | 748.19 | 2.44 |
| F x C x H | 1 | 3901.50 | 12.74 |
| O x C x H | 1 | 24.00 | 0.08 |
| S x F x C x H | 1 | 1.04 | 0.00 |
| S x O x C x H | 1 | 360.38 | 1.18 |
| F x O x C x H | 1 | 45.37 | 0.15 |
| S x F x O x C x H | 1 | | |
| Error | 16 | 306.18 | |
| Total | | | |

**p <.01
***p <.001

TABLE 9

ANOVA SUMMARY FOR AUDITORY ACTIVATION TASK
LEFT HEMISPHERE CONDITION

| Source | df | Mean Square | F-Test |
|---|---|---|---|
| Sex (S) | 1 | 5.02 | 0.02 |
| Foot (F) | 1 | 254.82 | 1.07 |
| Ord (O) | 1 | 41.49 | 0.18 |
| S x F | 1 | 291.84 | 1.23 |
| S x O | 1 | 0.08 | |
| F x O | 1 | 0.31 | 0.00 |
| S x F x O | 1 | 138.35 | 0.58 |
| Error (between) | 15 | 237.56 | |
| Cond (C) | 1 | 53.02 | 4.79* |
| S x C | 1 | 1.26 | 0.11 |
| F x C | 1 | 0.71 | 0.06 |
| O x C | 1 | 6.35 | 0.57 |
| S x F x C | 1 | 0.08 | 0.01 |
| S x O x C | 1 | 0.08 | 0.01 |
| F x O x C | 1 | 1.26 | 0.11 |
| S x F x O x C | 1 | 20.08 | 1.81 |
| Error (within) | 15 | 11.07 | |
| Total | 45 | 100.98 | |

*p <.05

TABLE 10

ANOVA SUMMARY FOR AUDITORY ACTIVATION TASK
RIGHT HEMISPHERE CONDITION

| Source | df | Mean Square | F-Test |
|---|---|---|---|
| Sex (S) | 1 | 15.19 | 0.06 |
| Foot (F) | 1 | 63.02 | 0.25 |
| Ord (0) | 1 | 35.02 | 0.14 |
| S x F | 1 | 1092.52 | 4.30 |
| S x 0 | 1 | 744.19 | 2.93 |
| F x 0 | 1 | 67.69 | 0.27 |
| S x F x 0 | 1 | 25.52 | 0.10 |
| Error (between) | 16 | 253.86 | |
| Cond (C) | 1 | 7.52 | 1.31 |
| S x C | 1 | 35.02 | 6.11* |
| F x C | 1 | 1.69 | 0.30 |
| 0 x C | 1 | 1.02 | 0.18 |
| S x F x C | 1 | 77.52 | 13.53** |
| S X 0 x C | 1 | 58.52 | 10.22** |
| F x 0 x C | 1 | 7.52 | 1.31 |
| S x F x 0 x C | 1 | 13.02 | 2.27 |
| Error (within) | 16 | 5.73 | |
| Total | 47 | 136.13 | |

*p <.05
**p <.01

TABLE 11

ANOVA SUMMARY FOR AUDITORY CRITERION TASK
LEFT HEMISPHERE CONDITION

| Source | df | Mean Square | F-Test |
|---|---|---|---|
| Sex (S) | 1 | 49047.05 | 0.87 |
| Foot (F) | 1 | 21840.30 | 0.39 |
| Ord (0) | 1 | 35046.41 | 0.62 |
| S x F | 1 | 8217.74 | 0.15 |
| S x 0 | 1 | 105267.63 | 1.87 |
| F x 0 | 1 | 128822.94 | 2.28 |
| S x F x 0 | 1 | 1612.85 | 0.03 |
| Error (between) | 18 | 56410.46 | |
| Cond (C) | 1 | 503853.44 | 26.06*** |
| S x C | 1 | 2310.40 | 0.12 |
| F x C | 1 | 466.98 | 0.02 |
| 0 x C | 1 | 5648.51 | 0.29 |
| S x F x C | 1 | 112572.25 | 5.82 |
| S x 0 x C | 1 | 4013.25 | 0.21 |
| F x 0 x C | 1 | 55950.28 | 2.89 |
| S x F x 0 x C | 1 | 60.85 | 0.00 |
| Error | 18 | 19336.64 | |
| Hemisphere (H) | 1 | 3946.74 | 1.17 |
| S x H | 1 | 1269.36 | 0.38 |
| F x H | 1 | 132.02 | 0.04 |
| 0 x H | 1 | 348.10 | 0.10 |
| S x F x H | 1 | 21006.10 | 6.22* |
| S x 0 x H | 1 | 16026.57 | 4.73* |
| F x 0 x H | 1 | 26557.01 | 7.86* |
| S x F x 0 x H | 1 | 30.05 | 0.01 |
| Error | 18 | 3379.30 | |
| C x H | 1 | 13322.36 | 7.19* |
| S x C x H | 1 | 173.61 | 0.09 |
| F x C x H | 1 | 2230.09 | 1.20 |
| 0 x C x H | 1 | 1269.36 | 0.69 |
| S x F x C x H | 1 | 2538.71 | 1.37 |
| S x 0 x C x H | 1 | 3789.48 | 2.05 |
| F x 0 x C x H | 1 | 12508.03 | 6.75* |
| S x F x 0 x C x H | 1 | 196.55 | 0.11 |
| Error | 18 | 1852.57 | |
| Total | 103 | 25220.22 | |

*p .05
***p .001

TABLE 12

ANOVA SUMMARY FOR AUDITORY CRITERION TASK
RIGHT HEMISPHERE CONDITION

| Source | df | Mean Square | F-test |
|---|---|---|---|
| Sex (S) | 1 | 164762.81 | 2.06 |
| Foot (F) | 1 | 145281.19 | 1.82 |
| Ord (0) | 1 | 67015.75 | 8.84 |
| S x F | 1 | 44667.81 | 0.56 |
| S x 0 | 1 | 121647.38 | 1.52 |
| F x 0 | 1 | 17590.93 | 0.22 |
| S x F x 0 | 1 | 32065.47 | 0.40 |
| Error (between) | 16 | 79980.81 | |
| Cond (C) | 1 | 376073.00 | 27.51*** |
| S x C | 1 | 10310.21 | 0.75 |
| F x C | 1 | 22815.37 | 1.67 |
| 0 x C | 1 | 41100.78 | 3.01 |
| S x F X C | 1 | 11744.45 | 0.86 |
| S x 0 x C | 1 | 2115.34 | 0.16 |
| F x 0 x C | 1 | 3069.05 | 0.22 |
| S x F x 0 x C | 1 | 7514.68 | 0.55 |
| Error | 16 | 13672.20 | |
| Hemisphere (H) | 1 | 290.02 | 0.10 |
| S x H | 1 | 876.47 | 0.30 |
| F x H | 1 | 317.65 | 0.11 |
| 0 x H | 1 | 1838.04 | 0.62 |
| S x F x H | 1 | 6165.16 | 2.09 |
| S x 0 x H | 1 | 4193.33 | 1.42 |
| F x 0 x H | 1 | 1529.62 | 0.52 |
| S x F x 0 x H | 1 | 612.75 | 0.21 |
| Error | 16 | 2952.87 | |
| C x H | 1 | 26.51 | 0.01 |
| S x C x H | 1 | 9.43 | 0.01 |
| F x C x H | 1 | 432.37 | 0.23 |
| 0 x C x H | 1 | 81.19 | 0.04 |
| S x F x C x H | 1 | 247.86 | 0.13 |
| S x 0 x C x H | 1 | 757.68 | 0.40 |
| F x 0 x C x H | 1 | 19.85 | 0.01 |
| S x F x 0 x C x H | 1 | 18.98 | 0.01 |
| Error | 16 | 1910.19 | |
| Total | 95 | 28015.82 | |

***p <.001

TABLE 13

ANOVA SUMMARY FOR VISUAL ACTIVATION TASK
LEFT HEMISPHERE CONDITION

| Source | df | Mean Square | F-Test |
|---|---|---|---|
| Sex (S) | 1 | 14.73 | 0.21 |
| Foot (F) | 1 | 33.97 | 0.48 |
| Ord (0) | 1 | 0.51 | 0.01 |
| S x F | 1 | 44.63 | 0.63 |
| S x 0 | 1 | 27.66 | 0.39 |
| F x 0 | 1 | 27.66 | 0.39 |
| S x F x 0 | 1 | 182.32 | 2.58 |
| Error (between) | 16 | 70.57 | |
| Cond (C) | 1 | 80.18 | 4.51* |
| S x C | 1 | 22.00 | 1.24 |
| F x C | 1 | 8.91 | 0.50 |
| 0 x C | 1 | 0.02 | 0.00 |
| S x F x C | 1 | 44.63 | 2.51 |
| S x 0 x C | 1 | 16.99 | 0.96 |
| F x 0 x C | 1 | 24.75 | 1.39 |
| S x F x 0 | 1 | 27.66 | 1.56 |
| Error (within) | 16 | 17.77 | |
| Total | 47 | 41.91 | |

*p <.05

TABLE 14

ANOVA SUMMARY FOR VISUAL ACTIVATION TASK
RIGHT HEMISPHERE CONDITION

| Source | df | Mean Square | F-Test |
|---|---|---|---|
| Sex (S) | 1 | 36.75 | 0.20 |
| Foot (F) | 1 | 140.08 | 0.78 |
| Ord (O( | 1 | 234.08 | 1.30 |
| S x F | 1 | 645.33 | 3.58 |
| S x O | 1 | 408.33 | 2.26 |
| F x O | 1 | 1.33 | 0.01 |
| S x F x O | 1 | 2.08 | 0.01 |
| Error (within) | 16 | 180.51 | |
| Cond (C) | 1 | 14.08 | 1.69 |
| S x C | 1 | 3.00 | 0.36 |
| F x C | 1 | 1.33 | 0.16 |
| O x C | 1 | 1.33 | 0.16 |
| S x F x C | 1 | 6.75 | 0.81 |
| S x O x C | 1 | 0.08 | 0.01 |
| F x O x C | 1 | 2.08 | 0.25 |
| S x F x O x C | 1 | 27.00 | 3.24 |
| Error (between) | 16 | 8.33 | |
| Total | 47 | 96.70 | |

APPENDIX C

CONSENT FORM

DEPARTMENT OF PSYCHOLOGY, UNIVERSITY OF NORTH DAKOTA

Consent Form of Research Participation

Research Project Description:

If you are part of the first set of subjects you will serve in the following two conditions. During one session, you will be asked to discriminate sequences of 3 numbers which are increasing or decreasing in value within a series of random numbers delivered via earphones and to indicate the sequence by pressing a foot pedal. Then, you will be asked to respond manually to a light presented on the right or left side of a panel by pressing a button on the same side of the panel that the light was flashed. After performing these tasks separately, you will be asked to perform the two tasks concurrently. During the second session you will be asked to discriminate sequences of 3 notes increasing or decreasing in frequency within a series of piano notes and to indicate the sequence by pressing a foot pedal. The rest of the session will be identical to the first session. That is, you will respond to light flashes alone, then perform the two tasks concurrently.

If you are part of the second set of subjects you will serve in the following two conditions. During one session you will be asked to discriminate sequences of 3 numbers which are increasing or decreasing in value within a series of random numbers presented visually and to indicate the sequence by pressing a foot pedal. Then you will be asked to respond manually to a tone presented to one ear by pressing a button with the hand on the same side of the body as the ear in which the tone was heard. After performing these tasks separately you will be asked to perform the two tasks concurrently. During the second session you will be asked to discriminate a sequence of 3 squares shifting horizontally to the right or the left within a series of squares presented on a strip of graph paper. Then the rest of the session will be identical to the first session. That is, you will respond to tones alone, then perform the two tasks concurrently.

You will be asked to complete the Health Opinion Survey, the Self-Evaluation Questionnaire and the Eysenck Personality Inventory

Subject's Consent:

I,______________________, voluntarily agree to participate in the research project as described above. I understand that I may discontinue my participation at any time and that my name will not be used in any reporting of the results of this study. I further understand that the researcher for this study has signed a paper on record endorsing the American Psychological Association's ethical standards for psychological research involving human subjects.

Subject's Signature______________________ Witness______________________

Date______________________

REFERENCES

## REFERENCES


Allport, D., Antonis, B., & Reynolds, P. On the division of attention: A disproof of the single channel hypothesis. Quarterly Journal of Experimental Psychology, 1972, 24, 225-235.

Anzola, G. P., Bertoloni, G., Buchtel, H. A., & Rizzolatti, G. Spatial comparability and anatomical factors in simple and choice reaction time. Neuropsychologia, 1977, 15, 295-302.

Beaton, A. A. Hemispheric function and dual task performance. Neuropsychologia, 1979, 17(6), 629-635.

Bertera, J. H., Callan, J. R., Parsons, O. A., & Pishkin, V. Lateral stimulus response comparability effects in the oculomotor system. Acta Psychologia, 1975, 39, 175-181.

Bocca, E., Calearo, C., Cassinari, V., & Megliavacca, F. Testing "cortical" hearing in temporal lobe tumors. Acta Pto-Laryngol, 1955, 45, 289-304.

Bogen, J. E. The other side of the brain II. An oppositional mind. In M. S. Gazzaniga (Ed.), The bisected brain. New York: Appleton-Century Crofts, 1970.

Bogen, J. E., & Gazzaniga, M. S. Cerebral commissurotomy in man. Minor hemisphere dominance for certain visuospatial functions. Journal of Neurosurgery, 1965, 23, 394-399.

Botkin, A. L., Schmaltz, L. W., & Lamb, D. H. "Overloading" the left hemisphere in right handed subjects with verbal and motor tasks. Neuropsychologia, 1977, 15, 591-596.

Bowers, D., Heilman, K. M., Satz, P., & Altman, A. Simultaneous performance on verbal, nonverbal and motor tasks by right handed adults. Cortex, 1978, 14, 540-556.

Briggs, G. A comparison of attentional and control shift models of the performance of concurrent tasks. Acta Psychologica, 1975, 39, 183-191.

Broadbent, D. E., & Gregory, M. On the interaction of S-R compatability with other variables affecting reaction time. British Journal of Psychology, 1965, 56, 61-68.

Brooks, L. R. Spatial and verbal components of the act of recall. Canadian Journal of Psychology, 1968, 22, 349-368.

Callan, J. R., Klisz, D., & Parsons, O. A. Strength of auditory stimulus response compatibility as a function of task complexity. Journal of Experimental Psychology, 1974, 102, 1039-1045.

Carmon, A. Spatial and temporal factors in visual perception of patients with unilateral cerebral lesions. In Kinsbourne, M. (Ed.), Assmetrical functions of the brain. Cambridge, England: Cambridge University Press, 1978.

Catlin, J., VanDervier, N., & Feicher, R. Monaural right-ear advantage in a target-identification task. Brain and Language, 1976, 3, 470-481.

DeRenci, E. Hemispheric asymmetry as evidenced by spatial disorders. In M. Kinsbourne (Ed.), Asymmetrical functions of the brain. Cambridge, England: Cambridge University Press, 1978.

Dick, A. O. Iconic memory and its relation to perceptual processing and other memory mechanisms. Perception and Psychophysics, 1974, 16, 575-596.

Dick, S., Rosenberg, S., & Karp, E. Hemispheric differences in simple reaction time to auditory stimuli of different frequencies. Perceptual Motor Skills, 1977, 44, 543-548.

Distefano, M., Morelli, M., Marzi, G. A., & Benlucci, G. Hemispheric control of unilateral and bilateral movements to proximal and distal parts of the arm as inferred from simple reaction time to lateralized light stimuli in man. Experimental Brain Research, 1980, 38, 197-204.

Fairweather, H. Sex differences in cognition. Cognition, 1976, 4, 231-280.

Filbey, R., & Gazzaniga, M. S. Splitting the normal brain with reaction time. Psychonomic Science, 1969, 17, 335-336.

Franco, L. Hemispheric interaction in the processing of concurrent tasks in commissurotomy subjects. Neuropsychologia, 1977, 15, 707-710.

Gazzaniga, M. S. The bisected brain. New York: Appleton-Century-Crofts, 1970.

Gazzaniga, M. S. One brain-two minds? American Scientist, 1972, 60, 311-317.

Gazzaniga, M. S., Bogen, J. E., & Sperry, R. W. Dyspraxia following division of the cerebral commissurer. Archives of Neurology, 1967, 16, 606-612.

Gazzaniga, M. S., & Sperry, R. W. Language after section of the cerebral commissurer. Brain, 1967, 90, 131-148.

Goldstein, K. Language and language disturbances. New York: Gruen & Stratton, 1948.

Hannay, H., & Malone, D. Visual effects and short-term memory for verbal material. Neuropsychologia, 1976, 14, 203-209.

Harcum, E. R. Lateral dominance as a determinant of temporal order of responding. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. Cambridge, England: Cambridge University Press, 1978.

Harris, L. J. Sex differences in spatial ability: Possible environmental genetic and neurological. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. Cambridge, England: Cambridge University Press, 1978.

Head, H. Aphasia and kindred disorders of speech. Cambridge, England: Cambridge University Press, 1926.

Hecaen, H. Aphasic, apraxic and agnostic syndromes in right and left hemisphere lesions. IN P. J. Vinken & G. W. Bruyn (Eds.), Handbooks of clinical neurology (Vol. IV). Amsterdam: North Holland Publishing Co., 1969.

Heron, W. Perception as a function of retinal locus and attention. American Journal of Psychology, 1957, 70, 38-48.

Hicks, R. E. Intra-hemispheric response. Competition between vocal and unimanual performance in normal adult human males. Journal of Comparative and Physiological Psychology, 1975, 89, 50-60.

Hicks, R. E., Provenzano, F. J., & Rybstein, E. D. Generalized and lateralized effects of concurrent verbal rehearsal upon performance of sequential movements of the fingers by the left and right hands. Acta Psychologica, 1975, 39, 119-130.

Jasper, H. H., & Raney, E. T. The physiology of lateral cerebral dominance. Psychological Bulletin, 1937, 34, 151-165.

Jeeves, M. A. A comparison of interhemispheric transmission times in a callosals and normals. Psychonomic Science, 1969, 16, 245-246.

Jeeves, M. A., & Dixson, N. F. Hemisphere differences in response rates to visual stimuli. Psychonomic Science, 1970, 20, 249-251.

Johnson, O., & Kozma, A. Effects of concurrent verbal and musical tasks on a unimanual skill. Cortex, 1977, 13, 11-16.

Kahneman, D. Attention and effort. Englewood Cliffs, N.J.: Prentice-Hall, 1973.

Kerr, B. Processing demands during mental operations. Memory and Cognition, 1973, 1, 401-412.

Kimura, D. Dual functional asymmetry of the brain in visual perception. Neuropsychologia, 1966, 4, 275-285.

Kimura, D. Functional asymmetry of the brain in dichotic listening. Cortex, 1967, 3, 163-178.

Kinsbourne, M. A model for the mechanism of unilateral neglect of space. Transactions of American Neurological Association, 1970, 95, 143-146.

Kinsbourne, M. The control of attention by interaction between the cerebral hemispheres. In S. Kornblum (Ed.), Attention and performance IV. New York: Academic Press, 1973.

Kinsbourne, M., & Cook, J. Generalized and lateralized effects of concurrent verbalization on a unimanual skill. Quarterly Journal of Experimental Psychology, 1971, 23, 341-345.

Kinsbourne, M., & Hicks, R. E. Mapping cerebral functional space: Competition and collaboration in human performance. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. Cambridge, England: Cambridge University Press, 1978.

Lansdell, H. A sex difference in effect of temporal lobe neurosurgery on design preference. Nature, 1962, 194, 852-854.

Lahe, D., & Bryden, M. Handedness and sex differences in hemispheric asymmetry. Brain and Language, 1976, 3, 266-282.

Levy, J., & Trevarthen, C. Metacontrol of hemispheric function in human split brain patients. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 299-312.

Levy, J., Trevarthen, C., & Sperry, R. W. Perception of bilateral chimeric figures following hemisphere deconnection. Brain, 1972, 95, 61-78.

Lomas, J., & Kimura, D. Intrahemispheric interaction between speaking and sequential manual activity. Neuropsychologica, 1976, 14, 23-33.

Luria, A. R. Traumatic aphasia. The Hague: Mouton, 1970.

Luria, A. R. Aphasia reconsidered. Cortex, 1972, 8, 34-40.

Maccoby, E. E., & Jacklin, C. N. The psychology of sex differences. Oxford: University Press, 1975.

McFarland, K., & Ashton, R. The influence of brain lateralization of function on a manual skill. Cortex, 1978, 14, 102-111.

McFie, J. The diagnostic significance of disorders of higher nervous activity: Syndromes related to frontal, temporal, parietal and occipital lesions. In P. J. Vinken & G. W. Bruyn (Eds.), Handbooks of Clinical Neurology (Vol. IV). New York: Wiley, 1969.

McGlone, J., & Davidson, W. The relationship between cerebral speech laterality and spatial ability with special reference to sex and hand preference. Neuropsychologia, 1973, 11, 105-113.

McGlone, J., & Kertsz, A. Sex differences in cerebral processing of visual spatial tasks. Cortex, 1973, 9, 313-320.

McKeever, W. F., & Huling, M. P. Lateral dominate and tachistocopic word recognition performance obtained with simultaneous bilateral input. Neuropsychologia, 1971, 9, 15-20.

McLeod, P. Adult task response modality effect: Support for multiprocessor models of attention. Quarterly Journal of Experimental Psychology, 1977, 29, 651-667.

McLeod, P. Does probe RT measure central processing demand. Quarterly Journal of Experimental Psychology, 1978, 30(1), 83-90.

Metzger, R., & Antes, J. Sex and coding strategy effects on reaction time to hemispheric probes. Memory and Cognition, 1976, 4(2), 167-171.

Michon, J. A. A note on the measurement of perceptual motor load. Ergonomics, 1964, 7, 461-463.

Michon, J. A. Tapping regularity as a measure of perceptual motor load. Ergonomics, 1966, 9, 401-412.

Moscovitch, M. Language and the cerebral hemispheres. Reaction-time studies and their implications for models of cerebral dominance. In P. Pliner, T. Alloway & L. Krames (Eds.), Communication and Affect: Language and Thought. New York: Academic Press, 1973.

Moscovitch, M., & Catlin, J. Interhemispheric transmission of information: Measurement in norman man. Psychonomic Science, 1970, 18, 211-213.

Murphy, E. H., & Venables, P. H. The investigation of ear asymmetry by simple and disjunctive reaction-time task. Perception and Phychophysics, 1970, 8, 104-106.

Nakamura, R., & Saito, H. Preferred hand and reaction time in different movement patterns. Perceptual Motor Skills, 1974, 39, 1275-1281.

Nebes, R. Direct examination of cognitive function in the right and left hemispheres. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. Cambridge, England: Cambridge University Press, 1978.

Ogden, W., Martin, D., & Paap, K. Processing demands of encoding: What does secondary task performance reflect. Journal of Experimental Psychology; Human Perception and Performance, 1980, 6(2), 355-367.

Pieters, J. M. Ipsilateral and contralateral reactions to monaural lateralized stimuli. Cortex, 1979, 15(2), 313-320.

Posner, M. I., & Boies, S. T. Components of attention. Psychological Review, 1971, 78, 391-408.

Posner, M. I., & Klein, R. M. On the functions of consciousness. In S. Kornblum (Ed.), Attention and performance IV. New York: Academic Press, 1973.

Semmes, J. Hemispheric specialization: A possible clue to mechanism. Neuropsychologia, 1968, 6, 11-26.

Simon, J. R., Hinrichs, J., & Craft, J. Auditory S-R compatability: Reaction time as a function of ear-hand correspondence and ear-response-location correspondence. Journal of Experimental Psychology, 1970, 86, 97-102.

Smith, E. E. Choice reaction times: An analysis of the major theoretical positions. Psychological Bulletin, 1968, 69, 77-110.

Sperry, R. W. Cerebral organization and behavior. Science, 1961, 33, 1749-1757.

Sperry, R. W. Lateral specialization in the surgically separated hemispheres. In F. O. Schmitt & F. G. Worden (Eds.), The neurosciences third program of study. Cambridge, Mass.: MIT Press, 1974.

Sperry, R. W., Gazzaniga, M. S., & Bogen, J. E. Interhemispheric relationships: The neocortical commissures; syndromes of hemisphere disconnection. In P. J. Vinken & G. W. Bruyn (Eds.), Handbook of clinical neurology. New York: Wiley, 1969.

Studdert-Kennedy, M., & Shankweiler, D. Hemispheric specialization for speech perception. Journal of the Acoustical Society of America, 1970, 48, 579-594.

Swanson, J., Ledlow, A., & Kinsbourne, M. Lateral asymmetrics revealed by simple reaction time. In M. Kinsbourne (Ed.), Asymmetrical function of the brain. Cambridge, England: Cambridge University Press, 1978.

Treisman, A. M., & Davis, A. Divided attention to ear and eye. In S. Kornblum (Ed.), Attention and performance IV. New York: Academic Press, 1973.

Trevarthen, C. Experimental evidence for a brain-stem contribution to visual perception in man. Brain Behavior and Evolution, 1970, 3, 338-352.

Weinstein, E. A. Hemiinattention and hemisphere specialization. New York: Raven Press, 1977.

Weinstein, S. Functional cerebral hemispheric asymmetry. In M. Kinsbourne (Ed.), _Asymmetrical function of the brain._ Cambridge, England: Cambridge University Press, 1978.

White, M. J. Laterality differences in perception: A review. _Psychological Bulletin_, 1969, _72_, 386-405.

Wyke, M. The effects of brain lesions on the performance if bilateral arm movements. _Neuropsychologia_, 1971, _9_, 33-43.

Zaidel, D., & Sperry, R. W. Some long-term motor effects of cerebral commurotomy in man. _Neuropsychologia_, 1977, _15_, 193-204.