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Hemispheric Effects of Response Hand and Concurrent Auditory and Visual Information Processing on Task Performance

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Hemispheric effects of response hand and concurrent auditory and visual information processing on task performance

by

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ABSTRACT

Hemispheric effects of response hand and concurrent auditory and visual information processing on task performance

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Previous research (cf. Wickens, Mountford & Schreiner, 1981; Wickens & Sandry, 1982) has suggested that performance is facilitated by maintaining "integrity" between the hemisphere of information input, processing, and motor response. This task-hemispheric integrity has been found to exist during concurrent performance of verbal and spatial tasks, both of which are presented in a visual modality. The present study sought to examine whether task-hemispheric integrity exists during concurrent performance of a verbal and a spatial task when the verbal task is presented in an auditory modality and the spatial task(s) are presented in a visual modality. Fifty-six individuals (28M, 28F) performed an auditory dichotic listening task alone and concurrently with three spatial tasks, each loading on a different stage of information processing. The results indicate a differential effect of each of the spatial tasks on dichotic listening performance, with few reciprocal effects of the dichotic listening task on spatial task performance. Sex differences were also found on two of the spatial tasks. Potential theoretical and practical implications of the findings are discussed.

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Human beings are uniquely suited for absorbing information from their surrounding environments, modifying and/or interpreting this information, and acting upon it if necessary. The human operator is amazingly proficient at performing these "information processing" tasks. In fact, much of the information that is received, processed, and acted upon is done so in an automatic, unconscious manner. However, there are situations that arise during which the human operator must actively perform multiple information-processing tasks simultaneously. With today's advances in technology, it is often the case that computers or robotics take over simple, routine, manual tasks, leaving the human to execute concurrent performance of a number of cognitive tasks. This recent shift in emphasis away from manual tasks frequently results in excessive mental demands being placed on the human operator. Most often in situations such as these, this remarkable information-processing proficiency deteriorates, and performance on one or more of the tasks declines. Clearly, there are limitations to the amount of information that a human can adequately process at any given time.

Early Theories of Information Processing

"Bottleneck" Theory

A number of theories have been proposed, in recent years, to describe the human as an information processor. Early theories described the human in terms of an information channel whose purpose was to transmit information between two sources. Broadbent (1958) described these capacity limitations in terms of a "bottleneck" in the system. This was a hypothetical internal mechanism which acted to process incoming information and to determine the channel capacity of the individual. It was hypothesized that all sensory inputs were initially processed in parallel and held in a short-term store. However, at some central processing stage, these information inputs reached a limited capacity decision channel. In order to reduce processing load, a hypothetical "filter" was invoked to block selectively some of the information before it reached the bottleneck. In this way, the system was able to regulate and optimize the amount and nature of information to be processed at any given time -- and only information relevant to the task at hand were processed fully. Broadbent believed that additional tasks could enter the central processor for processing whenever the current task did not completely exhaust the capacity of the processor. Thus, although all information passing through the filter was processed, only a limited amount of information could be processed and stored simultaneously. This limited capacity channel was believed to account for the decline in task proficiency during the added information load of multiple task performance.

Mental Resource "Pools"

Other "single channel" theories have also been proposed to describe the way in which humans process information. One of the more popular theories described the human as having a "pool" of mental resources with which to process information. For example, Kahneman (1973) proposed a single, undifferentiated pool of resources available for use with all types of tasks, regardless of their nature. Kahneman suggested that as the demands of a task increased, certain physiological arousal mechanisms were able to produce an increase in the available supply of processing resources -- but only up to a certain point. Beyond this point, increases in task demands exceeded the available resources and performance decrements would be seen.

Although the filter theory and other single channel theories offered viable initial attempts at describing human information-processing mechanisms, there are research findings that can not readily be explained by single channel/undifferentiated resource theories (cf. Cherry, 1953; Fairbanks, Guttman & Miron, 1957; North, 1977; Stroop, 1935; Wickens, 1980), thus suggesting that the "single channel" and "undifferentiated resource pool" metaphors appear to be inadequate descriptors of human information processing.

Recent Theories of Information Processing

Multiple Resources

Limitations in these early theories prompted the exploration of the human information processor as one which invokes multiple, qualitatively different resources. These multiple resource theories (e.g., Friedman, Polson, Dafoe & Gaskill, 1982; Navon & Gopher, 1979; Wickens, 1980) propose that a number of different resource capacities exist, and that multiple task performance may require different combinations of resources. To the extent that two tasks draw from common or overlapping resources, they were thought to interfere with each other and result in performance decrements.

In his multiple resource theory, Wickens (1980) proposed that processing resource structures vary along three dichotomous dimensions: early versus late processing stages, auditory versus visual processing modalities, and verbal versus spatial processing codes. Once again, Wickens argued that to the degree that tasks require common resources along these three dimensions, multiple task performance will be degraded.

In considering the processing stages dimension, Wickens hypothesized that resources invoked during early stages of processing (i.e., perceptual and central processing) are similar to one another and are functionally distinct from those resources invoked during late stages of processing (i.e., selection and execution of a response). A number of studies provide evidence that processes involved in response selection require qualitatively different resources than those involved in perceptual processing (Gopher, Brickner & Navon, 1982; Isreal, Wickens, Chesney & Donchin, 1980; Wickens, Kramer, Vanasse & Donchin, 1983).

In addition to the stage of processing, the modality of a task was also believed to influence human information processing. For example, a number of studies (e.g., Rollins & Hendricks, 1980) have found that humans are better able to perform concurrent tasks when task requirements distribute attentional demands between different modalities (e.g., eye and ear), than when tasks require the use of the same modality. It is suggested that tasks of each modality draw from separate resource pools and thus, when performed concurrently, do not exhaust the resources of a single pool. However, in a recent article (Wickens & Liu, 1988), Wickens claims that the attribution of specific, separate resources to different modalities may not be appropriate. Findings of recent studies suggest that it is the cost of visual scanning, rather than an actual overburdening of the visual modality resource, that frequently results in degraded performance in intramodal (visual-visual) task performance. When the processing cost of scanning is eliminated, the advantage of crossmodal (auditory-visual) task performance is reduced. Thus, although still relevant at a practical level, Wickens and Liu suggest that the application of processing modalities at a theoretical level may not provide as much utility in describing human information processing as the other two (i.e., stages and codes) dimensions.

Finally, the processing codes dimension is one which has received a great deal of interest, in one form or another, among the research community. The processing codes dimension differentiates those tasks which require verbal/linguistic processing from those which require spatial processing. A number of studies (e.g., Baddeley, 1986; Kinsbourne & Hicks, 1978; Polson & Friedman, 1988) have found that tasks requiring verbal and spatial processing appear to utilize separate processing resources. As Wickens and Liu (1988) note, the dimension of processing codes appears to be relevant to all three stages of information processing -- stimulus input, central processing, and response output. For example, in many applied settings information which is presented for processing is either of a verbal (e.g., written text, auditory speech information) or a spatial (e.g., geometric forms, vectors, spatial orientations, analog representations) nature. It is often the case that system designers are able to choose whether to present information verbally (e.g., a verbal description of vector coordinates) or to present that same information spatially (e.g., a pictorial representation of the vectors in space). Thus it may be useful to examine the relative processing requirements of verbal versus spatial presentation of information. In addressing the central processing stage, a number of researchers (e.g., Baddeley, 1986; Wickens & Sandry, 1982) have identified distinct spatial and verbal working memory systems which are used to perform separate types of information processing. These working memory systems are invoked during the central processing of a task. It is believed that the nature of a task (i.e., verbal versus spatial) will determine which working memory system will process the task. Finally, the verbal/spatial dichotomy is also appropriate for differentiating response processes such as those requiring verbal speech from those requiring spatially guided motor movements such as keyboard strokes or joystick movements. Findings from a study comparing single and dual task performance on combinations of a verbal and a spatial memory task offer support for the existance of at least partially independent resources which vary along stage (central processing versus response) as well as verbal versus spatial processing dimensions (Pritchard & Hendrickson, 1985).

Task-hemispheric Integrity Hypothesis

Background

In light of this, researchers have examined various combinations of verbal and spatial task components (i.e., input, central processing, output) in order to determine those arrangements of task components which lead to most proficient task performance. Work in this area by Wickens and his colleagues has led to the introduction of the concept of task-hemispheric integrity. Task-hemispheric integrity refers to a design arrangement in which the task stimuli, hemisphere of central task processing, and side of motor response are configured in such a way as to maintain a maximum degree of compatibility and thus, task proficiency. The concept of task-hemispheric integrity was introduced by Wickens, Mountford & Schreiner (1981) when it was noted that, during concurrent performance of verbal and spatial tasks, some arrangements of task stimuli and allocation of responses resulted in more proficient performance than other arrangements. This efficiency was shown to be especially applicable to situations in which the human operator is required to perform two or more tasks concurrently. As was noted earlier, the changing demands of the workplace have imposed an increasingly complex information-processing burden on the human operator, taxing the limits of the human's information-processing capability. Humans are constantly required to input, process, and respond to changing sources of verbal and spatial information. Thus, the potential for increased proficiency in task performance is an important and relevant issue, and techniques are continually being sought, both in equipment and task design, to improve information-processing and thus, multiple task performance. The use of task-hemispheric integrity in system design may prove to be a useful guideline for improving dual task efficiency.

Premises

Task-hemispheric integrity is based on several premises. First, a majority of information presented to one visual field is initially projected to the contralateral hemisphere. Second, the cerebral hemispheres exercise dominant control of contralateral motor movements. Finally, the two cerebral hemispheres are believed to be differentially specialized to process certain kinds of information. An understanding of each of these premises, as well as their inter-relatedness, is important and necessary to understanding the concept of task-hemispheric integrity. Therefore each, in turn, will be briefly discussed.

Research Support of Premises

In support of the first premise, physiological evidence indicates that the visual pathways project half of their visual information to the contralateral hemisphere (cf. Brown & Deffenbacher, 1979, pp. 275-277). Information projected to the right visual field is sent to the left (verbally proficient) hemisphere, while information projected to the left visual field is sent to the right (spatially proficient) hemisphere. In fact, a number of studies have found that lateralized presentation of information favors a right visual field/left hemisphere presentation of verbal information and a left visual field/right hemisphere presentation of spatial information (e.g., Friedman, Polson, Dafoe & Gaskill, 1982; Herdman & Friedman, 1985; Wickens & Sandry, 1982). In fact, Hellige (1975) and Kimura (1973) have found that humans are better able to recognize, and respond more quickly to, tachistoscopically presented verbal information when that information is presented to the right visual field (left hemisphere) than to the left visual field. Further, they found that nonverbal information presented in this manner resulted in either no hemispheric preference or resulted in faster, more accurate responses when the information was presented to the left visual field (right hemisphere) than to the right visual field. These lateralized differences in responses support the notion that the left and right hemispheres may be differentially specialized to process verbal and spatial information. Kimura (1966; 1973) suggested that these laterality effects occurred because the information presented to one visual field had direct access to the central processing mechanism located in the contralateral hemisphere. Thus, when information was presented to the visual field with direct access to the hemisphere proficient at processing that type of information, it resulted in better performance than when presented to the other visual field.

Regarding the second premise, it is generally accepted that motor tasks which do not require specific time sequencing (i.e., rhythm) are controlled by the hemisphere contralateral to the side executing the task (Kee, Hellige & Bathurst, 1983; Kinsbourne & Cook, 1971; Kinsbourne & Hicks, 1978). This means that the left hemisphere controls motor movements for the right side, and the right hemisphere controls motor movements for the left side. For tasks that require rhythm, performance is somewhat different. Peters (1977) examined the effects of concurrent performance of two motor tasks. Subjects were required to tap rapidly and continuously with the index finger of one hand while simultaneously beating a specified rhythm with the index finger of the other hand. Order of hand of task performance was counterbalanced across subjects. Only 10% of the 150 subjects were able to perform these tasks simultaneously. In a subsequent phase of the study, Peters asked subjects to recite the nursery rhyme "Humpty Dumpty" (with the proper rhythmic intonation) while simultaneously beating the specified rhythm from the earlier phase. No subjects were able to perform these tasks successfully. Based on the results of this research, Peters hypothesized that the central nervous system has the capacity to produce only one basic rhythm at a time while simultaneously executing voluntary motor movements. He proposed that for right-handed individuals, when the left hemisphere produces the basic rhythm (i.e., recitation of nursery rhyme, rhythmic tapping of the right hand), the right hemisphere is overruled and tends to follow the rhythm produced by the left hemisphere. However, in cases in which the right hemisphere produces the dominant rhythm (i.e., rhythmic tapping of the left hand), the left hemisphere is still capable of controlling simple motor movements such as finger tapping. In general however, for tasks which do not require these types of specific rhythmic sequences, motor movements are controlled by the contralateral hemisphere.

Finally, considering the third premise, for most right-handed individuals, it is believed that the left hemisphere is used to process language and verbal information, while the right hemisphere is principally involved in processing spatial information (Harshman, Hampson & Berenbaum, 1983). Converging evidence from various fields--including neuropsychological reports of disrupted speech after left but not right hemisphere injury or ablation (e.g., Broca, 1861) and increased electrophysiological responding in the left hemisphere but not the right with auditory verbal stimulation (Maximillian, 1982; Mazziotta, Phelps, Carson & Kuhl, 1982), to right ear proficiency during monaural and dichotic verbal stimulation (e.g., Murray & Richards, 1978; Springer, 1973)--support the notion of hemispheric specialization.

A number of studies have compared right and left hand performance of motor tasks, independently and while performing a concurrent verbal task. In theory, performance with the right hand (which is controlled by the left hemisphere) should be impaired to a greater extent as compared to the left hand during concurrent performance of a verbal task. Converging evidence for motor movements performed with the hand (e.g., Kinsbourne & Cook, 1971;

Lomas & Kimura, 1976; McFarland & Ashton, 1975) and the foot (Carnahan, Elliott & Lee, 1986) have found greater right-side motor task impairment than left-side during performance of a concurrent verbal task, lending support to this notion.

Many of these concurrent motor task/verbalization studies, however, required subjects to make overt vocalizations as responses to the verbal task. It was argued by some (e.g., Lomas & Kimura, 1976; Lomas, 1980) that the right hand interference was caused by a similarity in motor task requirements between the manual task and overt speech, rather than by hemispheric lateralization of verbal tasks per se. However, recent studies have found that verbal tasks performed without overt vocalization also interfered with right hand motor performance, to only a slightly lesser degree than with overt vocalization (Hellige & Longstreth, 1981; Ikeda, 1987; McFarland & Ashton, 1978). This indicated that concurrent <u>cognitive</u> verbal processing interfered with contralateral manual activity. As such, Hellige & Longstreth (1981) attempted to determine if concurrent cognitive spatial processing would also interfere with contralateral (i.e., left hand) motor performance. They found that performance of a spatial block design problem interfered more with left hand motor responses than with right hand responses. Interestingly, as Friedman et al. (1982) note, it appears that both hemispheres can process both types of information to varying degrees. However, the left hemisphere appears to be better suited for processing verbal information and the right hemisphere better suited for processing spatial information.

Research Findings on Task-hemispheric Integrity

In light of these findings, the notion of an integrity assignment suggests that verbal tasks should be positioned to the right and performed by the right hand (thus, both central processing and response are under the control of the language-processing proficient left hemisphere), and spatial tasks should be positioned to the left and responses made by the left hand (thus, both central processing and response are under the control of the spatial-processing proficient right hemisphere).

The potential for an improvement in task performance during situations of high workload through proper arrangement of stimulus and response allocation is particularly appealing. In testing the effects of integrity versus non-integrity assignments during single and dual task conditions, Wickens et al. (1981) found no performance advantage for integrity assignments under single task conditions. However, they did find an advantage for integrity assignments in the dual task condition. They hypothesized that under single task conditions, assignment to the same hemisphere of both stimulus processing and response control resulted in competition for the limited resources of that hemisphere. Thus, there was an advantage to distributing the task demands (processing and response) across the two hemispheres. This type of competition for resources between stimulus processing and response hand has been observed in a number of other studies (e.g., Alwitt, 1981; Gross, 1972; McFarland & Ashton, 1978). However, during concurrent performance of a verbal and a spatial task, both hemispheres were required for cognitive task processing. In this case, the integrity assignment (i.e., use of the same hemisphere for stimulus and response processing) resulted in more proficient performance than did the non-integrity assignment.

Wickens has conducted a number of studies examining the effects of various factors on the strength of the task-hemispheric integrity effect. For example, Carswell & Wickens (1985) found that a reduction in the degree of physical separation between the visually presented verbal and spatial tasks greatly diminished the task-hemispheric integrity advantage, most likely because there was no longer direct access of the stimuli to the appropriate cerebral hemisphere. In addition, they found that allocation of control of both tasks to the same hand completely eliminated any advantage of integrity stimulus arrangements.

Auditory Information Processing Requirements Implications for Task-hemispheric Integrity

Most of the studies examining task hemispheric integrity have looked at integrity among two different visually presented tasks. However, in actual applied settings human operators frequently encounter situations during which they must perform visual tasks while simultaneously receiving, processing, and responding to auditory information. Since the auditory neural pathway is similar to the visual pathway in that a majority of auditory information arrives first in the contralateral hemisphere (cf. Brown & Deffenbacher, 1979, pp. 190-191), a logical question would be "Does task hemispheric integrity also apply to tasks performed in combined visual/auditory modalities"? That is to say, is there any advantage to allocating auditory stimuli and responses to a particular hemisphere during concurrent performance of a visual task, if one task is predominantly verbal in nature and the other is predominantly spatial? If this were the case, it would be of theoretical interest and of potential practical relevance to determine those combinations of ear of auditory stimulus input (i.e., hemisphere of initial/primary stimulus reception) and response hand that lead to most proficient task performance during concurrent performance of a visual task and under various levels of task load.

Theoretical Requirements

In order to be able to assess task-hemispheric integrity during performance of an auditory task, it would first be necessary to control the hemisphere initially receiving the auditory stimulus. Although auditory stimuli travel bilaterally through the cochlear nerve to the cochlear nuclei, the great majority of auditory fibers cross over to the contralateral superior olive and continue on to the contralateral hemisphere. There is evidence from neurophysiological studies, as well as from auditory monaural and dichotic listening studies, that there is a stronger representation in the brain of auditory stimuli presented to the contralateral ear. For example, studies of brain activity found that larger auditory evoked potentials (Celesia, 1976) as well as faster evoked responses (Majkowski, Bochenek, Bochenek, Knapik-Fijalkowska & Kopec, 1971) were made to contralateral rather than ipsilateral ear stimulation.

Methodological Tools

The dichotic listening technique is one which has been used extensively in examining hemispheric lateralization (e.g., Geffen & Caudrey, 1981; Kimura, 1961). During a dichotic listening trial, messages are presented simultaneously to both ears. Transmission of information presented to the left ear is strongly represented in the right hemisphere, whereas transmission of information presented to the right ear is strongly represented in the left hemisphere. Thus, in research assessing task-hemispheric integrity in combined visual/auditory modalities, the use of a dichotic listening technique allows control over the ear of target signal input and hence, the hemisphere of primary auditory stimulus reception.

A number of studies have reported a right ear advantage (REA) in the identification of dichotically-presented verbal information (e.g., Kimura, 1967; Studdert-Kennedy & Shankweiler, 1970). Since the majority of information presented in the right ear reaches the left hemisphere first, this REA is believed, in part, to reflect left hemisphere specialization for verbal information. Furthermore, other studies (e.g., Springer, 1971) have found shorter RTs to verbal stimuli presented to the right ear during dichotic stimulus presentations. Interestingly, when examining dual-task performance of combined auditory and visual tasks, evidence from a number of studies (e.g., Acosta & Simon, 1976; Simmon & Pouraghabagher, 1978) has shown that irrelevant auditory cues seem to affect various stages of visual task performance differentially. In a study presenting a monaural or binaural tone concurrent with a visual choice RT task, auditory information seemed to interfere with the response selection stage of the visual task but not to interfere with the stimulus encoding stage. These results were similar for conditions in which the auditory stimulus provided relevant information to which subject responses were also required. This evidence provides an interesting point for which to explore task-hemispheric integrity between a concurrent auditory verbal and a visual spatial task. That is, perhaps it is the case that visual tasks which predominantly load on different stages of spatial cognitive processing (e.g., stimulus encoding, response selection) may be differentially affected by concurrent auditory verbal stimuli.

Hemispheres of Processing

Background

Another line of research, known as the "hemispheres of processing" approach also examines the role of the cerebral hemispheres in multiple task performance (Friedman & Polson, 1981; Friedman, Polson, Dafoe & Gaskill, 1982; Herdman & Friedman, 1985). Friedman and her colleagues offer partial support for the task-hemispheric integrity principle. However, they suggest that the dichotomies used to categorize tasks in this and other multiple resource theories may not accurately describe the processes that occur during task performance. In fact, their theory predicts somewhat different outcomes of multiple task performance in certain cases than does the task-hemispheric integrity hypothesis.

Premises

These authors postulate that a qualitative difference exists between the resources of the two hemispheres. They suggest that resources from one hemisphere cannot be shared with the other hemisphere, even if beneficial to task performance. For example, they propose that verbal information presented to the left visual field (right hemisphere) will still be processed by the right hemisphere, even though the left hemisphere might be more proficient at processing it. Further, they suggest that the resources of each hemisphere are undifferentiated and can execute, to varying degrees of proficiency, the information-processing necessary to complete all necesssary stages of task processing (i.e., perceptual, cognitive, motor). In addition, the resources in a given hemisphere can be used to perform any task which requires them. However, they note that while both hemispheres can be used to process all kinds of information, the left hemisphere is more proficient at processing verbal information, while the right hemisphere appears to be better able to process spatial information. All this leads them to conclude that two tasks requiring resources from different hemispheres should not interfere with one another beyond the cost of concurrence (cf. Navon & Gopher, 1979), but that two tasks requiring resources from the same hemisphere should interfere with each other (or at least show performance trade-offs based on task emphasis). Of interest, however, is the fact that recent research examining performance trade-offs during concurrent performance of rapid finger-tapping and a verbal memory task showed that a verbal read-aloud task interfered equally with tapping speed for both hands, leading these authors to suggest that processing resources required for different types of tasks (e.g., cognitive and motor) performed within each hemisphere might be independent of one another (Friedman, Polson & Dafoe, 1988).

Implications of Hemispheres of Processing Approach

This again has potential implications for task and equipment design because it suggests that two tasks with ostensibly few similarities can interfere with each other if they require resources from the same hemisphere. Furthermore, it would indicate that during single task dichotic listening trials, performance within a given hemisphere (i.e., left ear/right hemisphere/left hand, right ear/left hemisphere/right hand) will be better than performance requiring a response from across the two hemispheres (i.e., left ear/right hemisphere/right hand, right ear/left hemisphere/left hand). This is contrary to the predictions of the task-hemispheric integrity hypothesis which suggests that during single task trials, performance is improved when the task demands are distributed across the hemispheres. Also, the task-hemispheric integrity hypothesis suggests that during concurrent performance of verbal and spatial tasks, performance is improved if the hemisphere of input, central processing and output is the same for a given task. However, it is uncertain as to whether different types of tasks within a hemisphere might potentiate these effects when performed with tasks processed in the opposite hemisphere. Friedman and her colleagues offer only cautious support to the task-hemispheric integrity principle, suggesting that varying the stimulus or response modality, or combining verbal tasks with spatial will not necessarily reduce workload if the tasks still require overlapping resources from a single hemisphere.

Pilot Studies in the Area

Pilot studies have been performed in this laboratory using the dichotic listening technique to examine the effects of ear of input and response hand during concurrent performance of a visual spatial task and an auditory verbal task. The results indicate an interaction between the ear of stimulus input, response hand, and level of task load.

Reaction times (RTs) to target stimuli presented to the left ear increased for both hands during the dual task condition, while RTs to target stimuli presented to the right ear did not increase. It is hypothesized that this increase in left ear RTs during the dual task condition occurred because of the concurrent right hemisphere demands to process the spatial information. Although significant, these effects accounted for only a small portion of the variance. Similarly, small task-hemispheric integrity effects have also been reported in other studies (e.g., Wickens, et al., 1981).

Small Effects

One possible explanation for this may be that the small effects were a result of the type of spatial task used. In the pilot studies, a low-fidelity flight simulator task was used as the spatial task. This task primarily imposed perceptal-motor processing demands in a spatial domain. It is possible that this type of spatial processing did not consume as much of the total right hemisphere resources as might other types of spatial tasks. Thus, performance did not benefit greatly from integrity assignment. Another way of interpreting these results is to consider that the "hemispheres of processing" approach is correct in predicting that there is no overlap in the processing resources across the hemispheres, thus accounting for the relatively small differences between different hand/ear assignments. However, in view of the evidence reported by several earlier studies regarding differences in intra-hemispheric processing demands, examination of several different types of spatial tasks varying in their spatial processing demands might offer insight into the robustness of the task-hemispheric integrity phenomenon in a combined visual/auditory task situation.

Spatial Processing Demands

In light of this, a number of different functions believed to be essential to human performance in complex systems (Alluisi, 1967) were reviewed. Several of these functions appear to be related to spatial processing demands and can be assessed by certain spatial tasks. These functions are: perceptual-motor abilities, sensory-perceptual abilities, and cognitive types of abilities (e.g., memory functions). Each of these functions is believed to impose a separate kind of processing demand on the human operator, and are consistent with the "stages of processing" reported by Wickens (1980). Thus, it may be the case that the degree of task-hemispheric integrity during performance of concurrent visual spatial and auditory verbal tasks will vary with the processing demands imposed by the spatial task (i.e., type of right hemisphere processing requirements). If the evidence suggesting that different types of spatial tasks impose different processing demands is correct, then one would expect to see differences in the degree to which integrity assignments benefit concurrent verbal performance. However, if the evidence presented by Friedman and her colleagues is correct and there is no interhemispheric overlap between the demands of the different tasks, then it is possible that performance on the verbal task will not differ as a function of the type of concurrent spatial task.

Purpose of Research

The present study seeks to determine the effects of three different types of spatial processing demands -- perceptual-motor, sensory-perceptual, and memory -- on task-hemispheric integrity during concurrent performance of an auditory verbal task. The study will attempt to address the following questions: 1) Is the task-hemispheric integrity or the hemispheres of processing (Friedman) hypothesis a better description of multiple task performance? 2) Does task-hemispheric integrity exist during concurrent performance of verbal and spatial tasks across combined auditory/visual modalities? By this we mean, "Is there any differential effect of ear of verbal stimulus input (i.e., hemisphere of primary verbal stimulus reception) and/or side of motor response to verbal and spatial tasks during a dual task situation?" and, 3) Do the types of processing demands imposed by a concurrent spatial task (i.e., sensory/perceptual, central processing, perceptual/motor) differentially affect performance on a verbal task? Thus, the purposes of the present study are to determine the effects on task-hemispheric integrity of: 1) ear of stimulus input, 2) response hand, and 3) type of spatial processing resource demands time-shared with a verbal dichotic listening task.

Method

Subjects

Fifty-six right-handed individuals (28 males, 28 females) participated in the present experiment. All subjects had 20/20 vision (either uncorrected or corrected) and had normal conversational hearing. Subjects were between the ages of 18 and 29 years (median age = 20 yrs.).

Experimental Tasks

A dichotic listening (DL) task and three spatial tasks -- spatial processing (SP), display monitoring (DM), and unstable tracking (UT) -- were used in this research. The tasks were selected from the Criterion Task Set (modified by the Air Force Aerospace Medical Research Laboratory/Human Engineering Group - AAMRL/HEG) which was developed out of multiple resource theories to impose loads on basic processing resources. Each spatial task was designed to impose a different type of spatial processing demand on the subject. Each task has been validated and has been found to place a highly selective, primary demand on one of the three processing resources identified (i.e., sensory/perceptual, cognitive, perceptual/motor), while placing a minimal load on the remaining two resource dimensions. The spatial processing task was selected to impose a cognitive central processing load. It required short term memory for spatial relations among groups of shapes. The display monitoring task imposed spatial sensory-perceptual processing demands. Finally, the unstable tracking task imposed perceptual-motor demands in a spatial domain. Each spatial task was performed at a moderate level of difficulty as determined by AAMRL/HEG and later validated by Amell, Eggemeier & Acton (1987).

Dichotic Listening Task

This task required subjects to listen to 52 dichotic word pairs presented aurally over a set of headphones. Subjects were instructed to listen in both ears for a target word (i.e., "DOG") and to respond as quickly as possible by pressing a joystick button when they heard the target word in either ear. Subjects were instructed to direct equal attention to the stimuli input in each ear. One half of the subjects responded to this task with their right hand, and the other half responded with their left hand. The stimuli were presented at approximately 70 dB, well above the threshold levels of each subject. Reaction time and number of hits and false alarms were recorded during each trial of the dichotic listening task.

Spatial Processing Task

The SP task is based on a similar task developed by Chiles, Alluisi & Adams (1968). It was designed to impose cognitive processing demands of mental manipulation and comparison of spatial information. This task required subjects to view and compare pairs of histograms. Each histogram was composed of four bars of heights varying randomly from 1 to 6 units. No two bars in a histogram were the same height. The first histogram in each pair was presented on the screen in an upright position and remained on the screen for a period of 3 seconds. During this time the subject attempted to memorize the relative sizes and positions of the bars in the histogram pattern. After the first histogram disappeared from the screen, a second histogram appeared on the screen rotated 90 or 270 degrees from the first. The second histogram remained on the screen until the subject made a response, up to a maximum period of 2.5 seconds. The subject was required to unrotate mentally the second histogram and to indicate, as quickly as possible, whether the second histogram was the same as or different from the first histogram. Subjects were required to respond during the time interval between the onset of the comparison histogram and the following 2.5 seconds during which the comparison was on the screen. Subjects indicated their decision by pressing a specified button for a "same" response or another specified button located two inches from the first for a "different" response. Subjects started each trial with their response hand resting in a neutral position between the two buttons, and were instructed to keep their hand in this position at all times during the task. Reaction time, number correct and number incorrect were recorded during the spatial processing task.

Display Monitoring Task

The DM task is based on a similar task developed by Chiles, Alluisi & Adams (1968). The task was designed to impose heavy visual sensory/perceptual demands on the human information processor. The task required subjects to monitor a set of two rectangular display dials on a computer screen. The displays appeared side-by-side on the computer screen, separated by a visual angle of approximately 30 degrees. Both displays consisted of a pointer and six pointer positions. During the task, the pointer moved randomly among the six positions at the rate of five moves per second. Ten times during the task, the pattern of pointer movement became nonrandom and the pointer tended to stay on one side of the dial more than the other. This nonrandom pattern was considered a "biased signal." The proportion of time that the pointer stayed on the favored side of the dial during a biased signal was 95 percent. This meant that 95% of the pointer moves were on the favored side, while 5% were still on the non-favored side, during a biased signal. When a signal occurred, the subject was required to press a button which corresponded to the dial on which the signal was occurring, indicating that he or she had noticed the biased signal. After a response was made, the dial returned to a random pattern of pointer movement. If the subject failed to respond to a signal within a period of 12 seconds (i.e., 60 pointer moves), the signal automatically returned to a random pattern and the subject received a "miss" for that signal. Reaction time and number of hits and misses were recorded during the display monitoring task.

Unstable Tracking Task

The UT task is based on a tracking task by Jex & Clement (1979). It was designed to impose heavy manual (perceptual/motor) demands on the human operator. This task required the subject to minimize the distance between a center target (represented as two small lines on the display screen) and a small vertical tracking bar moving horizontally across the screen. The system within which the operator worked was inherently unstable. Input errors made by the operator were magnified by the system. As a result, the operator was required to respond continuously to the bar's velocity, as well as to deviations from the target position. No external forces were applied to the system. Unstable system dynamics were caused by human tracking remnants and by noise in the response input digitization.

In addition, the tracking bar could not exceed the outer boundaries of the task (approximately 9.5 cm on either side of the target). If it did, it automatically reappeared back at the center target and began moving away once more. This was known as an "edge violation" and was recorded against the subject. The vertical bar moved away from the center of the screen in a random fashion. The subject was able to move the tracking bar back to the center by turning a knob clockwise (to move the bar to the right) and counterclockwise (to move the bar to the left). The bar moved away from the center of the screen at a moderately fast pace, and the displacement of the bar was slightly greater than the corresponding displacement of the knob. Root mean square (RMS) error and number of edge violations were recorded during the tracking task.

Materials and Apparatus

Dichotic Listening Task

The dichotic listening task employed a target identification paradigm like that of Geffen & Caudry (1981). An auditory stimulus tape with 52 dichotic word pairs presented at the rate of one pair every three to four seconds was used. The stimuli consisted of monosyllabic word pairs including a "target" word (i.e., DOG), several phonemic "distractor" words (e.g., HOG, DIG), and several dissimilar neutral words (e.g., FIN). Each stimulus was a three letter, consonant-vowel-consonant word. The target word was randomly presented ten times to each ear via a set of headphones. The target word was never presented on the first two or last trial, and was never paired with a distractor word. In addition, neither the target word nor the distractors occurred in succession to the same ear. There were a total of twenty presentations of the target stimulus during each trial. In order to control for any unintentional differences in signal intensity or clarity between the two ear channels, headphones were reversed for half of the subjects.

The auditory stimuli were played on a JVC stereo cassette deck and were presented to the subjects through a set of Koss SST/5 headphones. A voice-actuated relay was used to open a switch and start a clock. The subjects' responses (i.e., presses of a joystick button) closed the switch and reset the clock, and reaction time was recorded. If no response occurred to a stimulus within a period of two seconds after its presentation, the clock automatically reset and a "No response" was recorded for the trial. For those trials in which a target was presented, this was considered a "miss." The dichotic listening task was run on an IBM-type personal computer system, and RT data were printed out on an Epson LX-800 printer following each trial.

Spatial Tasks

The three spatial tasks were run on a Commodore-64 computer system. Responses were made either as button presses on a keyboard (SP and DM tasks) or as knob turns (UT task). Responses to the spatial tasks were printed out on an Epson LX-800 printer. The software driving the spatial tasks was the V2.0 version of the Criterion Task Set (CTS) modified by the AAMRL/HEG (Shingledecker, 1984).

Handedness Questionnaire

Finally, in order to assess right-hand dominance, a handedness survey (Annett & Kilshaw, 1982) was administered. On this questionnaire, subjects were required to report the hand which they used to perform a variety of motor tasks such as writing, throwing a ball, and threading a needle (see Appendix A). A right hand dominance "handedness" score was computed by dividing the total number of items by the number of items to which the subject responded "right." These handedness scores were later used as one predictor variable in a multiple regression analysis predicting right ear dominance on the dichotic listening task. One question was added to the survey (although not computed in the handedness score), inquiring the ear to which the subject most frequently holds the telephone. This dichotomous variable was also used as a predictor in the multiple regression analysis.

Experimental Variables

Independent

The independent variables examined on the dichotic listening task were response hand, ear of target word input, sex, and type of concurrent spatial task (i.e., no concurrent task, concurrent display monitoring, spatial processing, or unstable tracking task). For the three spatial tasks, the independent variables were response hand, sex, and task load (i.e., single task, dual task).

Dependent

The dependent variables measured in the present study varied by task. For the dichotic listening task, reaction time (RT) and percent correct by ear (hits, misses, false alarms) were recorded. During the spatial processing task, RT, number correct, number incorrect were recorded. For the display monitoring task, RT, number of hits, number of misses were recorded. Finally, during performance of the unstable tracking task, RMS error and number of edge violations were recorded.

Experimental Design

The experimental design for the dichotic listening task consisted of a 2 (response hand) x 2 (ear of input) x 2 (sex) x 4 (concurrent spatial task type -- no concurrent task, concurrent DM, SP or UT task) x 14 (subjects) repeated measures design with subjects nested in sex and response hand, and factorial to ear of input and spatial task type. The experimental design for each of the three spatial tasks consisted of a 2 (response hand) x 2 (sex) x 2 (task load) x 14 (subjects) repeated measures design with subjects again nested in sex and response hand, and factorial to task load.

The order of the four single task trials and the three dual task trials were counterbalanced using a Latin square design, resulting in a total of fourteen different task orders. Two female and two male subjects were placed in each of these task orders. One male and one female in each order were randomly assigned to the "right" hand condition, while the other male and female were assigned to the "left" hand condition.

Procedure

After entering the experimental room, subjects were briefed regarding the purpose of the experiment and were asked to sign an informed consent form and to complete a questionnaire assessing level of handedness. Next, subjects performed one 3-minute practice trial of each of the seven experimental task conditions (four single, three dual). All subjects performed the four single task trials in the same order (DL, DM, SP, UT). However, the order of the dual task trials was counterbalanced. There were 1-minute inter-trial intervals.

Prior to each single task practice trial, subjects received instructions regarding task performance, and were instructed as to which hand to use for each task (see Appendix B for task instructions). All questions were clarified. Subjects performed all tasks without experimenter assistance with one exception. During the first minute of the DM task, the experimenter remained with the subject and indicated several "biased signals" to the subject in order to familiarize the subject with these prior to experimental task performance. After completion of the four single task practice trials, subjects performed the three dual task practice trials. During dual task trials, subjects performed each spatial task concurrent with the dichotic listening task, and used the same hand for each as was used during the respective single task conditions. Subjects were instructed to try to pay equal attention to the two tasks. Upon completion of the practice trials, any remaining questions were answered. Subjects were then given the opportunity to take a 5-minute break prior to the actual experimental testing session.

During the experimental trials, task instructions were reviewed and subjects repeated the seven task trials. Tasks again lasted for a duration of 3 minutes, with a 1-minute inter-trial interval. Subjects used the same hand for each task as was used during the practice trials. The order of experimental task performance was counterbalanced using a Latin square design. Performance during each single task trial was used as a baseline for performance during the same dual task (concurrent DL) condition.

Upon completion of the experiment, subjects were debriefed and each was offered class credit for participating.

Results

Dichotic Listening Task

Reaction Time

Median reaction times (RTs) were computed for each subject across tasks on responses made to the target stimulus. A four-way (ear x hand x task x sex) repeated measures analysis of variance with subjects nested in sex and hand was performed on the median RT data. Table 1 presents a summary of the sources of variance for RT on the DL task.

Insert Table 1 about here

A significant main effect was seen for ear $F(1,52) = 7.67$, $p<.05$, with the average response to right ear targets faster than the average response to left ear targets (RE = 658.33 msec, LE = 693.39 msec). A significant main effect was also found for task $F(3,156) = 25.90$, $p<.05$. A Newman-Keuls test performed on the reaction time data across the four tasks indicated a significant difference between each of the four task levels. The fastest reaction times to the auditory target occurred during concurrent performance of the unstable tracking task, followed by the dichotic listening task alone, the concurrent spatial processing

Table 1

Sources of variance for the dichotic listening task RT data

Source of Variance	df	Mean Square	F	Eta Square
Within Subjects				
Ear	1	137683.425	7.67*	.012
Task	3	334542.170	25.90*	.084
Task x Ear	3	4489.451	.74	
Between Subjects				
Sex	1	290506.757	2.46	
Hand	1	58466.720	.49	
Hand x Sex	1	214436.254	1.81	
Mixed Factorial				
Hand x Ear	1	41199.407	2.30	
Sex x Ear	1	32320.418	1.80	
Hand x Task	3	17919.783	1.39	
Sex x Task	3	1016.726	.08	
Hand x Task x Ear	3	4750.651	.78	
Hand x Sex x Ear	1	2096.760	.12	
Sex x Task x Ear	3	4656.851	.77	
Hand x Sex x Task	3	2525.594	.20	
Hand x Sex x Task x Ear	3	5748.372	.95	
Sources of Error				
S(Sex Hand)	52	118311.190	NT	
Ear x S(Sex Hand)	52	17948.239	NT	
Task x S(Sex Hand)	156	12917.982	NT	
Task x Ear x S(Sex Hand)	156	6081.274	NT	

* Signifies p<.05

task, and finally, the longest RTs occurred during concurrent performance of the display monitoring task. Table 2 shows the average reaction times to the dichotic listening target stimulus across tasks.

Insert Table 2 about here

There were no other significant main effects and no significant interactions on the dichotic listening RT data.

Missed Target Signals

The number of target stimulus misses during performance of the dichotic listening task was also recorded for each subject across tasks. A four-way (ear x hand x task x sex) repeated measures analysis of variance with subjects nested in hand and sex was performed on the number of misses. The results of this analysis are shown in Table 3.

Insert Table 3 about here

A significant main effect was found for task $F(3,156) = 10.29$, $p<.05$. A Newman-Keuls test performed on the number of misses across tasks indicated that the number of misses for the dichotic listening task alone and during concurrent performance of the unstable tracking task were similar but

Table 2

Average reaction times (in msec) to the dichotic listening target stimulus across tasks

Task			
Unstable Tracking	Dichotic Listening	Spatial Processing	Display Monitoring
614.05	649.50	703.25	736.65

Table 3

Sources of variance for the number of misses on the dichotic listening task

Source of Variance	df	Mean Square	F	Eta Square
Within Subjects				
Ear	1	2.145	.76	
Task	3	14.080	10.29*	.029
Task x Ear	3	2.800	3.09*	.006
Between Subjects				
Sex	1	8.306	.51	
Hand	1	11.895	.74	
Hand x Sex	1	1.877	.12	
Mixed Factorial				
Hand x Ear	1	.181	.06	
Sex x Ear	1	.645	.23	
Hand x Task	3	.431	.31	
Sex x Task	3	1.627	1.19	
Hand x Task x Ear	3	.276	.30	
Hand x Sex x Ear	1	.270	.10	
Sex x Task x Ear	3	.431	.48	
Hand x Sex x Task	3	2.282	1.67	
Hand x Sex x Task x Ear	3	.234	.26	
Sources of Error				
S(Sex Hand)	52	16.139	NT	
Ear x S(Sex Hand)	52	2.839	NT	
Task x S(Sex Hand)	156	1.368	NT	
Task x Ear x S(Sex Hand)	156	.906	NT	

* Signifies p<.05

differed significantly from the number of target misses during concurrent performance of both the spatial processing and display monitoring tasks. The number of target misses during concurrent performance of these tasks did not differ from one another. The fewest number of misses occurred during performance of the DL task alone, with the greatest number of misses occurring during concurrent performance of the display monitoring task. Table 4 indicates the average number of dichotic listening target stimulus misses across tasks. There were no other significant main effects for number of misses.

Insert Table 4 about here

A significant interaction was found between task and ear of target stimulus input for number of misses, $\underline{F}(3,156) = 3.09$. $\underline{p}<.05$. A test for simple effects indicated that the average number of misses during the dichotic listening task alone and during concurrent performance of the display monitoring and unstable tracking tasks did not differ from right ear to left ear. However, during concurrent performance of the spatial processing task, the average number of misses was significantly greater for the left ear than for the right ear. Figure 1 illustrates this interaction. There were no other significant interactions

Table 4

Average number of misses to dichotic listening target stimulus across tasks

Task			
Unstable Tracking	Dichotic Listening	Spatial Processing	Display Monitoring
1.02	0.86	1.46	1.61

for number of misses on the dichotic listening task.

Insert Figure 1 about here

False Alarms

The number of false alarms (i.e., responses to distractor stimuli) made by each subject during performance of the dichotic listening task was extremely small. In fact, 41% of the subjects made no false alarms at all. Because of this, these data were not subjected to an analysis of variance. A summary of the frequencies of false alarms by task, ear, hand and sex is presented in Table 5.

Insert Table 5 about here

Right Ear Advantage

An index of right ear advantage (REA) was computed for each subject by task as the difference between the median right ear RT and the median left ear RT (i.e., RT(RE)-RT(LE)). A stepwise regression analysis was performed separately for each task in order to determine the degree to which scores on several factors predicted the REA. These factors included the following variables: sex, hand used to perform the DL task, degree of handedness (as indexed by the Annett (1982) handedness questionnaire), ear used for

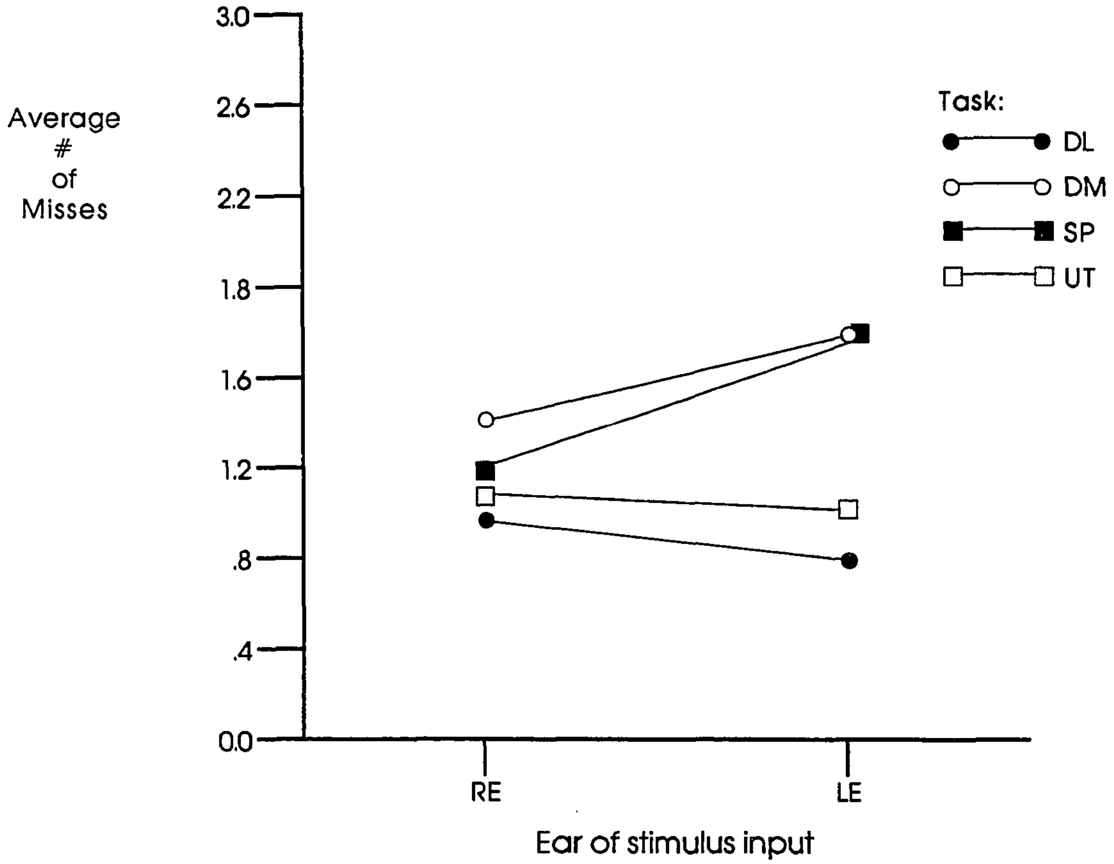

Figure 1. Interaction between task and ear for number of misses on the dichotic listening task.

Table 5

Summary of the frequencies of false alarms to distractor stimuli on the dichotic listening task by task, ear, hand and sex

Task	Males	Females
Dichotic Listening		
Right hand/Right ear	1	3
Right hand/Left ear	1	5
Left hand/Right ear	10	3
Left hand/Left ear	3	2
Display Monitering		
Right hand/Right ear	1	9
Right hand/Left ear	1	8
Left hand/Right ear	5	1
Left hand/Left ear	4	2
Spatial Processing		
Right hand/Right ear	4	3
Right hand/Left ear	0	5
Left hand/Right ear	7	5
Left hand/Left ear	8	3
Unstable Tracking		
Right hand/Right ear	1	4
Right hand/Left ear	1	6
Left hand/Right ear	7	3
Left hand/Left ear	7	5

telephone conversation, and, for the REA scores determined during dual-task trials, scores on the concurrent spatial task. Because these were exploratory analyses, the alpha level for significance was set at $p<.10$.

For the DL single task trial, two variables satisfied the criterion for entrance. Sex, $F(1,53) = 4.29$, $p = .043$, and hand of DL task performance, $F(1,53) = 3.47$, $p = .068$, accounted for 7.1% and 5.7% of the experimental variance, respectively. During the DL with the concurrent display monitoring task, only one variable satisfied the criterion for entrance. The hand of task performance, $F(1,54) = 3.00$, $p = .089$, accounted for 5.3% of the variance. No REA predictor variables satisfied the criterion for entrance during the concurrent performance of the spatial processing or unstable tracking tasks.

Spatial Tasks

Display Monitoring Task

During this task, ten "biased signals" were interspersed between random patterns of display pointer movement during each three-minute task trial. Measures of time to discriminate and respond to a biased signal, number of correct discriminations (hits) and number of missed signals were recorded for this task.

Reaction time. Median reaction times for responses to biased signals were computed for each subject for the single and dual task trials. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was performed on the RT data. No significant effects were found for the RT data. Table 6a shows the sources of variance for RT on the display monitoring task.

Insert Table 6 about here

Signal hits. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was computed on the number of signal hits during performance of the display monitoring task. Table 6b shows the sources of variance for misses. A significant main effect was found for hand, F(1,52) = 3.91, p<.05, with the number of hits for the right hand exceeding the number of hits for the left hand (RH = 6.4, LH = 5.5). There were no other significant effects for the number of misses.

Signal misses. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was performed on the number of signal misses. Table 6c shows the sources of variance for misses on the DM task. A significant main effect for task load F(1,52) = 4.24, p<.05, was found with fewer misses made

Table 6

Sources of Variance for RT, hits and misses on the Display Monitoring Task

Source of Variance	df	Mean Square	F	Eta Square
a. Reaction time				
Within Subjects				
Task load	1	1.051	.29	
Between Subjects				
Hand	1	1.130	.35	
Sex	1	.001	.00	
Hand x Sex	1	1.110	.34	
Mixed Factorial				
Hand x Task load	1	1.071	.30	
Sex x Task load	1	.444	.12	
Hand x Sex x Task load	1	.884	.25	
Sources of Error				
S(Sex Hand)	52	3.271	NT	
Task x S(Sex Hand)	52	3.578	NT	
b. Signal Hits				
Within Subjects				
Task load	1	5.580	2.12	
Between Subjects				
Hand	1	25.080	3.91*	.049
Sex	1	3.398	.61	
Hand x Sex	1	1.080	.17	
Mixed Factorial				
Hand x Task load	1	.723	.28	
Sex x Task load	1	8.580	3.27	
Hand x Sex x Task load	1	2.009	.76	
Sources of Error				
S(Sex Hand)	52	6.410	NT	
Task x S(Sex Hand)	52	2.627	NT	
c. Signal Misses				
Within Subjects				
Task load	1	8.580	4.24*	.011

Table 6 (continued)

Between Subjects				
Hand	1	16.509	1.44	
Sex	1	37.723	3.29	
Hand x Sex	1	.080	.01	
Mixed Factorial				
Hand x Task load	1	13.580	6.71*	.017
Sex x Task load	1	.080	.04	
Hand x Sex x Task load	1	25.080	12.40*	.031
Sources of Error				
S(Sex Hand)	52	11.465	NT	
Task x S(Sex Hand)	52	2.023	NT	

* Signifies $p<.05$

during single task performance than during dual task performance (single = 1.71, dual = 2.27). A significant interaction was found between hand and task load, F(1,52) = 6.71, $p<.05$. A test for simple effects indicated no difference in right hand and left hand performance during single task performance. However, as Figure 2 indicates, during dual task performance the number of misses for the left hand remained the same, while the number of misses for the right hand increased significantly. A significant interaction between hand, sex and task load was also found, F(1,52) = 12.40, $p<.05$. A test for simple effects indicated that the number of misses for males remained relatively constant, regardless of hand, from single to dual task trials. However, for females, the number of misses made with the left hand decreased from single to dual task trials, while the number of misses with the right hand increased from single to dual task trials. Figure 3 shows this interaction.

Insert Figures 2 and 3 about here

Spatial Processing Task

Measures of reaction time to each stimulus, and the number of correct and incorrect responses were recorded during performance of the spatial processing task. Since the

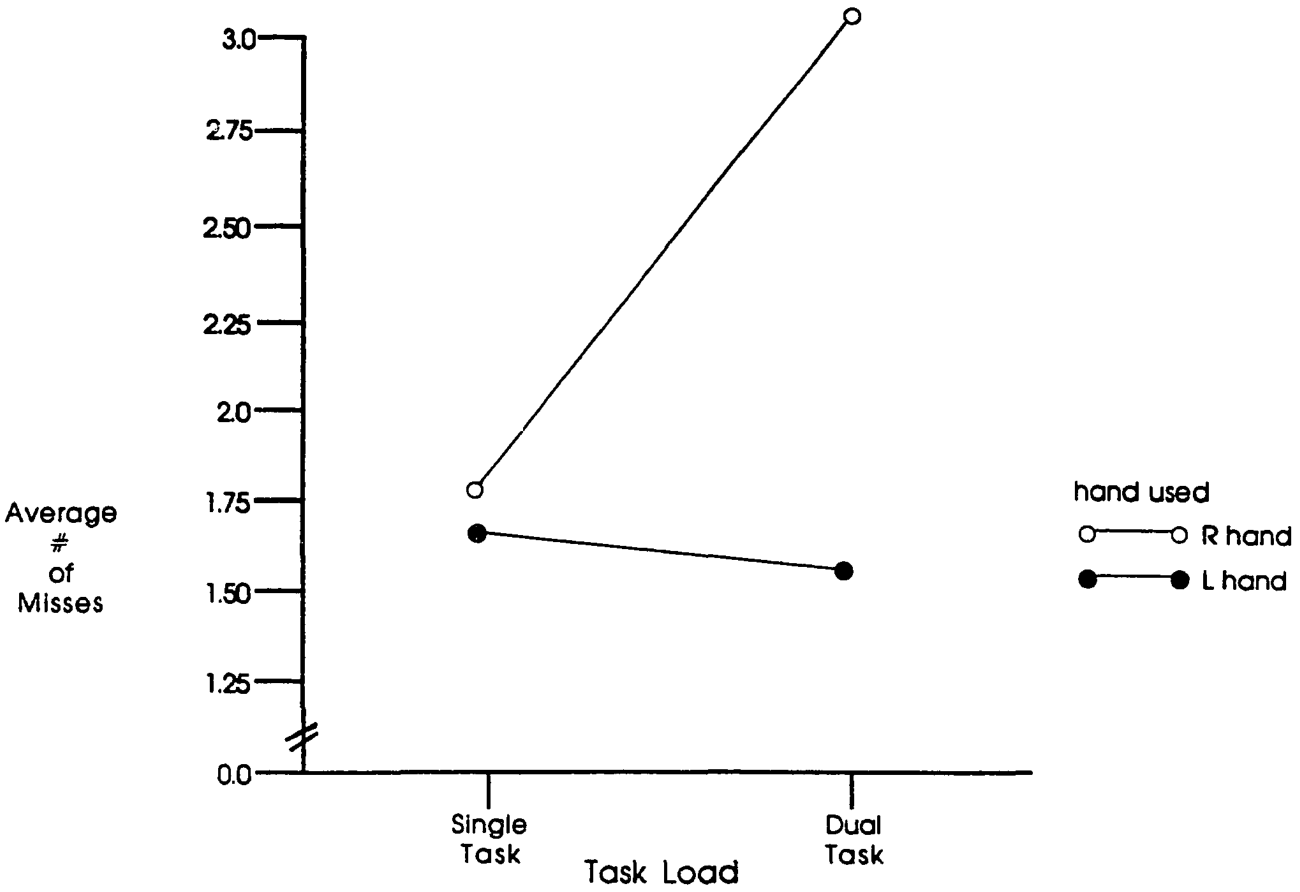

Figure 2. Interaction between hand and task load for number of signal misses on the display monitering task.

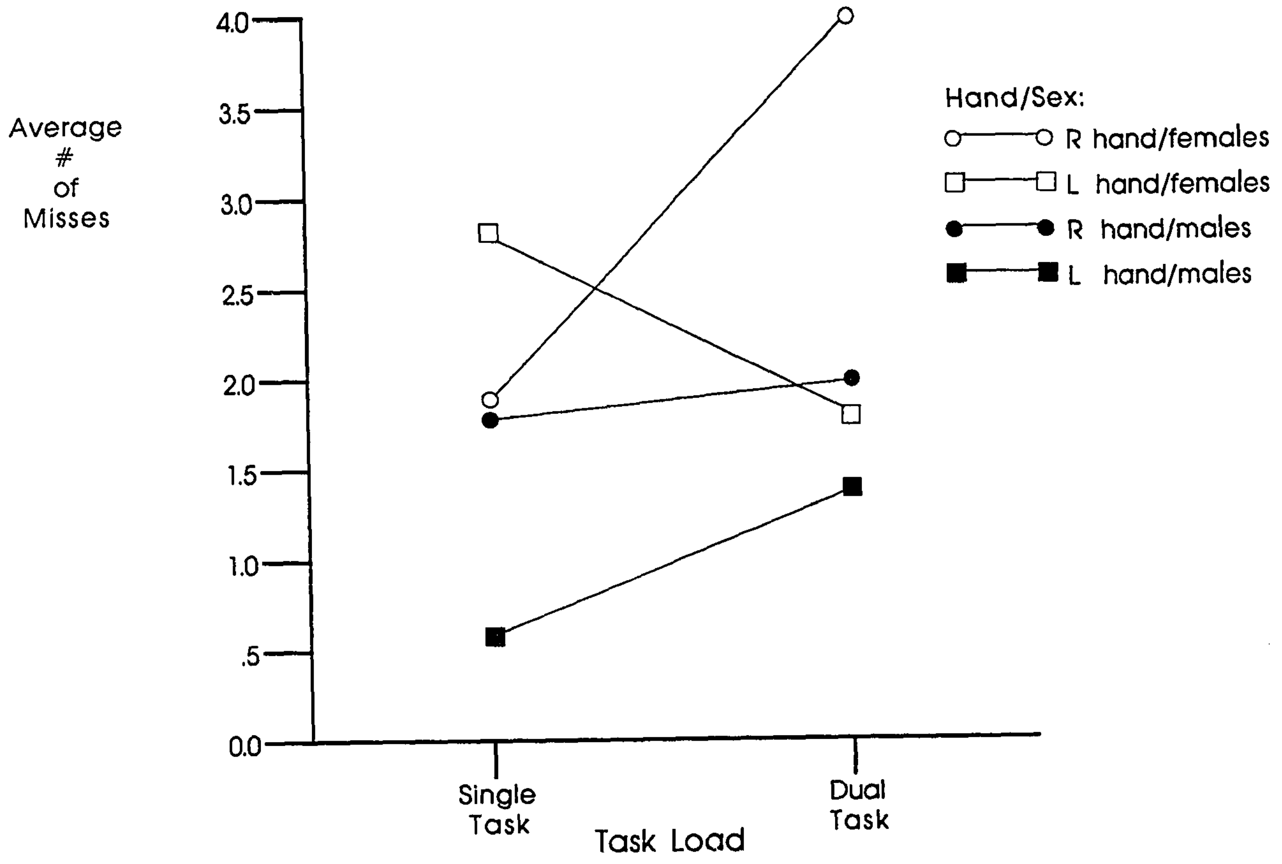

Figure 3. Interaction between hand, sex and task load for the number of signal misses on the display monitoring task.

total number of stimuli presented during this task was not fixed but rather, was a function of average RT, both the number of correct and the number of incorrect responses were analyzed.

Reaction time. Median reaction times were computed for each subject on the correct responses during single and dual task trials. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was performed on the RT data. Table 7a shows the sources of variance for reaction time during performance of the spatial processing task. As can be seen, no significant main effects or interactions were found for reaction time.

Insert Table 7 about here

Correct responses. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was computed on the number of correct responses to stimuli during the spatial processing task. A summary of the sources of variance for the number of correct responses is shown in Table 7b. A significant main effect for sex was found, $F(1,52) = 11.67$, $p<.05$, with males making a greater number of correct responses than females (M = 35.2, F = 32.6). There were no other significant main

Table 7

Sources of Variance for RT and number of correct and incorrect responses on the Spatial Processing Task

Source of Variance	df	Mean Square	F	Eta Square
a. Reaction time				
Within Subjects				
Task load	1	25020.321	2.79	
Between Subjects				
Hand	1	267.223	.00	
Sex	1	413586.036	3.32	
Hand x Sex	1	149431.080	1.20	
Mixed Factorial				
Hand x Task load	1	14197.509	1.58	
Sex x Task load	1	190.321	.02	
Hand x Sex x Task load	1	30591.080	3.41	
Sources of Error				
S(Sex Hand)	52	124721.980	NT	
Task x S(Sex Hand)	52	8980.428	NT	
b. Correct Responses				
Within Subjects				
Task load	1	.080	.02	
Between Subjects				
Hand	1	.009	.00	
Sex	1	182.580	11.67*	.143
Hand x Sex	1	3.938	.25	
Mixed Factorial				
Hand x Task load	1	5.580	1.08	
Sex x Task load	1	.080	.02	
Hand x Sex x Task load	1	.009	.00	
Sources of Error				
S(Sex Hand)	52	15.652	NT	
Task x S(Sex Hand)	52	5.149	NT	

Table 7 (continued)

c. Incorrect Responses

Within Subjects				
Task load	1	6.509	1.45	
Between Subjects				
Hand	1	.438	.04	
Sex	1	45.009	4.05*	.051
Hand x Sex	1	.723	.07	
Mixed Factorial				
Hand x Task load	1	2.009	.45	
Sex x Task load	1	1.508	.34	
Hand x Sex x Task load	1	9.723	2.17	
Sources of Error				
S(Sex Hand)	52	11.216	NT	
Task x S(Sex Hand)	52	4.476	NT	

* Signifies p<.05

effects and no significant interactions for number of correct responses during performance of the spatial processing task.

Incorrect responses. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was computed on the number of incorrect responses to stimuli during performance of the spatial processing task. Table 7c shows the sources of variance for the number of incorrect responses made during the spatial processing task. A significant main effect was found for sex, $F(1,52) = 4.05$, $p<.05$, with males making fewer incorrect responses than females (M = 3.5, F = 4.8). There were no other significant main effects or interactions for incorrect responses.

Unstable Tracking Task

Absolute average tracking error was computed as the RMS error of the instantaneous deviation samples taken at the rate of one per second. In addition, the number of edge violations (i.e., number of times the cursor hit the left or right boundaries of the task) was also recorded. For all subjects, data from the first 10 seconds of each trial were discarded in order to allow subjects to begin the task with relative cursor stability.

RMS error. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was performed on the deviation data. Table 8a shows the sources of variance for the RMS error on the unstable tracking task. Significant main effects for task load (single vs. dual) _F_(1,52) = 4.72, _p_<.05 and for sex _F_(1,52) = 11.03, _p_<.05 were seen. RMS error for the single task was significantly less than for the dual task (single = 29.27, dual = 30.77), and males outperformed females (males = 26.04, females = 34.00). There were no other significant main effects and no significant interactions on the deviation data for the UT task.

Insert Table 8 about here

Number of edge violations. A three-way (hand x task load x sex) repeated measures analysis of variance with subjects nested in sex and hand was performed on the number of edge violations. The sources of variance for the number of edge violations are shown in Table 8b. A significant main effect was seen for sex, _F_(1,52) = 7.55, _p_<.05, with males making significantly fewer edge violations than females (M = 11.7, F = 36.7). A significant interaction was also seen between sex and task, _F_(1,52) = 6.72, _p_<.05. As Figure 4 illustrates, male performance improved slightly from the single to the dual task trial, while female

Table 8

Sources of Variance for RMS tracking error and number of edge violations for the Unstable Tracking Task

Source of Variance	df	Mean Square	F	Eta Square
a. RMS tracking error				
Within Subjects				
Task load	1	63.300	4.72*	.006
Between Subjects				
Hand	1	274.063	1.70	
Sex	1	1776.036	11.03*	.158
Hand x Sex	1	59.743	.37	
Mixed Factorial				
Hand x Task load	1	.013	.00	
Sex x Task load	1	12.356	.92	
Hand x Sex x Task load	1	4.400	.33	
Sources of Error				
S(Sex Hand)	52	161.018	NT	
Task x S(Sex Hand)	52	13.407	NT	
b. Number of Edge Violations				
Within Subjects				
Task load	1	371.571	1.59	
Between Subjects				
Hand	1	217.286	.09	
Sex	1	17500.000	7.55*	.113
Hand x Sex	1	1889.286	.81	
Mixed Factorial				
Hand x Task load	1	276.571	1.18	
Sex x Task load	1	1575.000	6.72*	.010
Hand x Sex x Task load	1	357.143	1.52	
Sources of Error				
S(Sex Hand)	52	2319.352	NT	
Task x S(Sex Hand)	52	234.379	NT	

* Signifies $p<.05$

performance deteriorated.

Insert Figure 4 about here

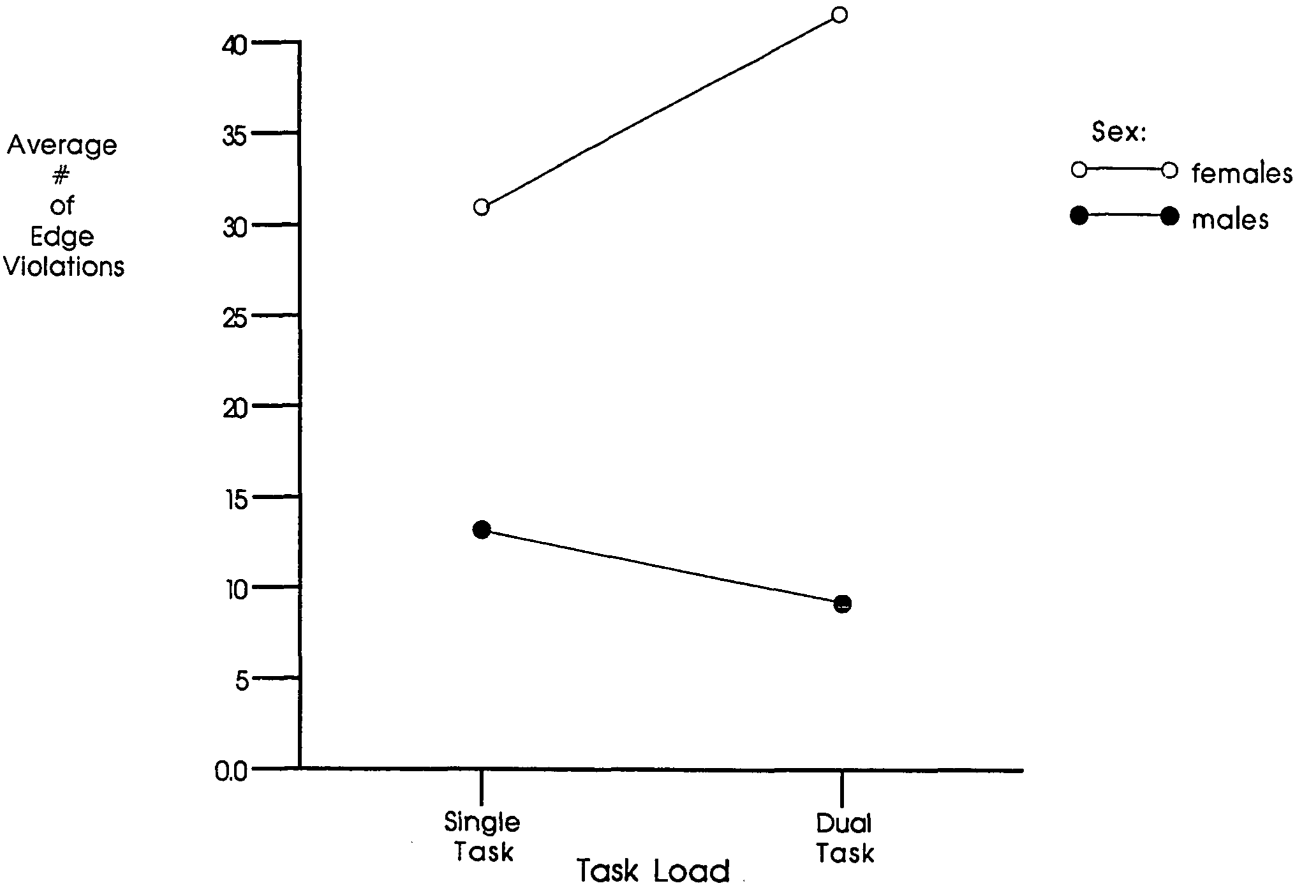

Figure 4. Interaction between sex and task load for the number of edge violations on the unstable tracking task.

Discussion

The findings of the present study, taken as a whole, offer only partial support to the notion of "task-hemispheric integrity." Interestingly, they suggest that the ability to time share an auditory verbal task and a visual spatial task is, in fact, dependent upon the degree to which the two tasks share common resources. It appears that this effect is mediated by the stage of processing required by the tasks. Although the task-hemispheric integrity hypothesis suggests that performance in a dual task situation using two visual tasks is facilitated by maintaining integrity between the hemisphere of central processing and response hand, this effect was not completely replicated for combined visual/auditory tasks. That is, although performance on the two tasks was affected by the type of processing required, it did not differ as a function of hand used.

For clarity of presentation, the results of the present study will be discussed in four sections. Section I will discuss DL task performance; Section II will discuss spatial task performance; Section III will discuss theoretical implications, and Section IV will present the potential utility of this type of research as well as implications of the present research paradigm for future research.

Dichotic Listening Task Performance

Previous research using the dichotic listening technique (e.g., Geffen, 1980; Kimura, 1961; Ley & Bryden, 1982) has found what is typically referred to as a "right ear advantage" (REA). That is, individuals seem to respond more quickly and more accurately to verbal stimuli presented to the right ear than to the left ear. Since verbal input must ultimately arrive at the left hemisphere for processing, this REA is believed to result from the more direct contralateral auditory pathways from the right ear to the left (i.e., language processing) hemisphere, as compared to the route for left ear input via either the weak ipsilateral or the indirect contralateral-and-crossing auditory pathways. Data from the present study were consistent with the notion of an REA for verbal stimuli. Although inter-ear accuracy (in terms of number of misses) did not differ, subjects responded on average, approximately 35 msec faster to stimuli input to their right ear than to their left ear. This finding, although not of direct relevance to the objectives of the present study, is fundamental in confirming the basic supposition that the verbal stimuli used in the DL task primarily imposed left hemisphere processing requirements.

Of greater interest is the finding that the processing demands imposed by the performance of concurrent spatial tasks differentially impacted performance on the DL task. In fact, in terms of RT, performance in all four conditions (i.e., DL alone and simultaneous with three spatial tasks) was significantly different. One surprising result, as Table 1 indicates, is the fact that the DL task alone did not result in the fastest RTs to the auditory targets. It appeared that concurrent performance of the UT task actually facilitated RT on the DL task, whereas concurrent performance of the SP and DM tasks slowed RT. This differential effect cannot be attributed to test arousal or fatigue, since all experimental conditions were counterbalanced.

Reaction time to the auditory targets during concurrent performance of the UT task decreased from single task baseline by an average of 35.5 msecs. Two explanations appear plausible for this reduction in RT. The first of these relates to the subjects' focus of attention, while the second relates to the possibility of dual task facilitation. In considering the first hypothesis, it is possible that during concurrent performance of the UT task, subjects focused more attention on the auditory task than they did during concurrent performance of the other two tasks. If greater attention were focused on the DL task, it would seem reasonable to expect that the RTs to auditory targets would be faster during the UT task than during the other two tasks. Also, if more attention were focused on the auditory task, it would seem that performance on the UT task would show greater single to dual task deficits than the DM or SP tasks, since less attention would have been paid to it. In order to infer how much attention was being paid to the spatial tasks during concurrent performance of the auditory task, spatial task performance data must be briefly examined. For the UT task, accuracy (in terms of RMS error) did significantly decrease from single to dual task trials, and for females, it also significantly decreased in terms of the number of edge violations. This decrement in performance on the UT task during dual task trials would suggest that, for this concurrent task pair, subjects may have been focusing a greater amount of attention on the auditory task instead of paying equal attention to both tasks. It might also be argued that these decrements in performance on the UT task were simply due to a "cost of concurrence" -- the price of performing two tasks at once. However, since the other two spatial tasks showed little or no performance deficits from single to dual task trials, this is not a likely explanation. In examining the performance data for the other two spatial tasks (DM and

SP), the lack of significant differences between single and dual task trials suggests that there was not a dramatic shift in attention away from the spatial task towards the auditory during the dual task trials. For the display monitoring task, there was no difference between single and dual task performance in terms of RT and number of signal hits. However, signal misses did increase slightly during dual task performance. Also, for the spatial processing task, there was no difference in speed or accuracy of performance from single to dual task trials.

Thus, based on the fact that performance during dual task trials did decline for the UT task but did not substantially change for the DM and SP tasks, it seems possible that subjects may have been focusing more attention on the auditory task during concurrent performance of the UT task than during concurrent performance of the other two tasks. However, since significant declines in spatial task performance did not occur across tasks, it was evident that subjects showed no systematic bias to shift their attention to the auditory task and away from the spatial tasks during dual task trials. Furthermore, even if subjects were focusing more attention on the DL task during concurrent performance of the UT task, this would suggest that RT to the auditory stimuli should have simply remained constant from the single task baseline levels. A differential attention factor would not seem to explain why RT actually decreased significantly during dual task performance.

An alternative explanation may be that the improvement in the speed of performance on the DL task during concurrent performance of the UT task may have actually resulted from dual task facilitation. A number of other researchers have observed such facilitation during concurrent performance of certain tasks (cf. Friedman, Polson, Dafoe & Gaskill, 1982; Wickens & Liu, 1988). For example, Wickens & Liu (1988) found that the concurrent performance of a tracking task with a verbal task or a spatial task caused deficits in the performance of both of these tasks (i.e., a dual task RT decrement). However, it was found that there was a reduction in the RT decrement with increasing verbal task demands, while there was no such reduction in the RT decrement with increasing spatial task demands. These results, although only marginally significant, support the notion of dual task facilitation. These authors suggest that the increased task demand imposed by the dual task trials mobilized additional resources not available during single task trials. The increased task demands imposed by the tracking task were speculated to generate resources which were not required for performance of the tracking task, but which were available for use to facilitate performance on the concurrent verbal or spatial task. They noted that performance facilitation was most likely to occur if the processing demands imposed by the second task were different from those required by the first task.

This is, in fact, the case with the tasks in the present study. The DL task required a predominance of left hemisphere processing, but also required right hemisphere activity during left ear inputs in order to transfer information to the left hemisphere via the corpus callosum. It is hypothesized that the right hemisphere resources required by the tracking task shared little overlap with the right hemisphere requirements of the DL task. This is most likely the case because the right hemisphere requirements of the DL task emphasized input processes and information transfer of left ear inputs, whereas the right hemisphere requirements for the UT task were primarily to aid in perceptual/motor responses in a spatial domain. However, the increased level of right hemisphere activation caused by the UT task may have served to mobilize additional right hemisphere resources which were then available to facilitate the input and transfer of auditory information to the left hemisphere -- thus, resulting in faster RTs to the auditory stimuli during dual task trials than during single task trials. Furthermore, the number of auditory target stimuli that were missed during the concurrent UT task did not increase from single task levels, while this number did increase significantly during concurrent performance of the other two spatial tasks. This finding supports the notion that the resources used for inter-hemispheric transfer of information during the UT task were able to maintain the fidelity of the auditory signal, while those available for use during the other two tasks resulted in degraded signal transfer. Thus, the decreased RT, together with the fact that the number of target stimulus misses during the concurrent UT task did not increase, lends support to the notion that right hemisphere activation during performance of the UT task resulted in additional processing resources (relative to those available during the DM and SP tasks) which were made available for use on the DL task. The availability of these particular processing resources appeared to result in dual task facilitation for DL task performance.

In examining performance on the DL task during concurrent performance of the other two tasks, it is obvious that these tasks did not facilitate, but rather, impaired performance on the DL task. The SP task caused an average increase in RT of almost 54 msecs while the DM task caused an average increase of over 87 msecs. These increases were significantly different from one another, suggesting that the processing resources required for these tasks too, are differentially time-shared with the auditory task. Furthermore, concurrent performance of both of these tasks resulted in a significant increase in the number of missed auditory target stimuli. However, while the SP task resulted in significantly more misses for left ear inputs than for right ear inputs, the DM task caused increases in the number of missed targets in both ears.

This has interesting implications in terms of the multiple resources model. Before these are explored, however, one fundamental assumption must be reiterated. This assumption is that the three concurrent "spatial" tasks were indeed spatial in nature and did cause right hemisphere activation. A priori assumptions regarding right hemisphere activation were made based on previous research using similar or identical tasks which inferred right hemisphere activation.

The SP task was validated and shown to impose a heavy central processing load in a spatial domain (Chiles, Alluisi & Adams, 1968). As such, it was hypothesized to impose central processing demands on right hemisphere resources. Interestingly, the SP task did not interfere with recognition of auditory inputs in the right ear (left hemisphere). However, it did result in an increased average

RT to both ears and an increased number of misses to auditory target stimuli presented to the left ear. To the extent that the SP task did not interfere with recognition of right ear inputs but did interfere with left, suggests that the task primarily required right hemsiphere processing resources. In fact, it required sufficient right hemisphere resources (or resources similar to those required by the DL task for inter-hemispheric information transfer) to impair the transfer of concurrent left ear (right hemisphere) verbal information to the left hemisphere for processing. Thus, the right hemisphere resource demands of these two tasks "overlapped" and performance was degraded. However, performance on the DL task during the concurrent SP task suggests that the basic processing resources of the tasks, apart from those necessary to transfer auditory information to the left hemisphere, are at least somewhat independent. That is, it appears that a spatial task which loads on central processing resources (e.g., the SP task) will not interfere with the recognition of concurrent auditory verbal information, if that information is presented directly to the left hemisphere. This is evidenced by the fact that the number of misses to auditory signals presented in the right ear did not increase during the dual task trial. However, this type of spatial task does appear to increase RT required to recognize and respond to the stimuli.

The DM task, on the other hand, has been validated to load heavily on sensory/perceptual input processes (Chiles, Alluisi & Adams, 1968). Since the task of monitoring requires subjects to scan spatial movements and integrate these over time, and since there is evidence that dynamic analog displays are mentally represented as dynamic analog images (cf. Wickens, 1984, pp. 175-183), it was hypothesized that the DM task would invoke right hemisphere spatial processing resources. This task also produced increases in average RT to the auditory stimulus, but did not result in a unilateral increase in number of target misses. Rather, the concurrent DM task produced an increase in the number of misses to target stimuli in both ears. Upon subsequent consideration of the DM task requirements, it was determined possible that the DM task may actually have required some left hemisphere resources for task processing. For example, in addition to visually sampling and mentally representing the spatial data in analog form, subjects were required to combine this information with previous information and to make continuous decisions regarding the stage of the system -- a sort of executive processing. Other researchers (e.g., Carmon, 1978; Friedman, Polson & Dafoe, 1988; Peters, 1977) have found that the left hemisphere is involved in coordinating, scheduling and sequencing responses during simultaneous verbal and motor tasks, regardless of the hand of motor output. As such, the "executive" processing is believed to be mediated by the left hemisphere for simultaneous verbal and motor tasks. Although the DM task did not require overt vocalizations, it is nevertheless possible that the left hemisphere may have been required for the executive processing demanded by the DM task for continuous coordination of information and status evaluations. Thus, the DM task may have utilized processing resources from both hemispheres, contributing to the bilateral interference on the concurrent auditory task. In addition, it may be possible that the heavy demands for input processing resources during the combined DL and DM tasks (as opposed to the UT task) exceeded the total available attentional resources. Thus causing bilateral deficits in the DL task performance which were attributable not to an overload in the demand for processing resources of either hemisphere in specific, but rather, to a lack of available resources to input all of the required information simultaneously.

These results suggest that the stage of processing invoked upon the right hemisphere differentially affects the ability to perform a concurrent left hemisphere processing task. This supports a multiple resources model proposed by Wickens (1980) which was the basis for his task-hemispheric integrity hypothesis. Part of Wickens' model suggested that the stage of processing required for performance of a task affects the type of processing resource required. Wickens divided the processing stages into those that require perceptual/cognitive processing (e.g., information monitoring, diagnosis of situations, mental rotation) and those that require output response processes (e.g., button press, toggle manipulation, voice command). The DM and SP tasks used in the present study load on sensory/perceptual and central cognitive processes, respectively, and thus, fall into the former category, whereas the UT task loads primarily on perceptual/motor response processes and thus, falls into the latter category. The results of the present study suggest that when a verbal auditory task is performed concurrently with each of these spatial tasks, those tasks involving perceptual/cognitive processing interfere to a greater extent with the auditory task than do tasks primarily requiring output processes. Based on the RT data and on the number of auditory target misses, it might be stated that spatial tasks which emphasize input processes have the most detrimental effect on concurrent verbal processing, followed by those which emphasize central processing. However, one must use caution when making this assumption about the input load task (i.e., the DM task) from the present data, in light of the fact that the "spatial" input task presumed to invoke right hemisphere processing resources may have simultaneously invoked executive processing from the left hemisphere. It may have thus caused additional performance deficits in the DL task beyond those attributable to the requirements of spatial input processing per se. Finally, it appears that tasks involving central processing of spatial information (e.g., the SP task) consume more right hemisphere resources or consume resources similar to those required for transfer of verbal information to the left hemisphere, whereas spatial tasks which emphasize output responses (e.g., the UT task) consume less, or actually facilitate the processes necessary for interhemispheric information transfer.

Another factor of interest which has implications for equipment design is the impact of hand used to perform the tasks. Wickens and his colleagues (e.g., Wickens, Mountford & Schreiner, 1981; Wickens & Sandry, 1982) found that in a dual task situation, performance was facilitated if the hand used for task responding was mediated by the same hemisphere that performed the task processing. For example, during performance of concurrent visually-presented verbal and spatial tasks, performance was facilitated if the right hand (i.e., left hemisphere) responded to the verbal task and the left hand (i.e., right hemisphere) responded to the spatial task. The present study sought to examine whether this same principle was true for verbal and spatial tasks presented in combined auditory/visual modalities. There appeared to be no effect of hand on task performance for the dichotic listening task. In fact, the only effects found for hand of task performance was for the number of hits (i.e., correct signal detections) and misses during the display monitoring task. This finding will be addressed in the spatial task performance section.

It is possible that the lack of significant hand effects in the present study was due to the nature of the auditory stimulus presentation. That is, for the visual tasks used by Wickens, it was possible to present the stimuli exclusively to one or the other visual field, thus controlling the hemisphere of stimulus access. For the auditory stimuli used in the present study, however, the closest approximation to complete lateralized auditory stimulus presentation was obtained by presenting the auditory information dichotically. In this paradigm there is still some weak, and usually overridden, information which arrives at the hemisphere ipsilateral to stimulus input. Although the ipsilateral representation of information was weak, it may have served to "prime" the hemisphere on those trials in which the ipsilateral hemisphere was required to control the hand of motor response. If this were the case, differences might not be seen between the response times for information presented to the two ears.

Another possible explanation for the lack of significant differences between hands could lie in the simplistic nature of the motor response required. That is, the go-no-go button push in response to auditory targets required very little cognitive organization of motor output. In a study using lateralized presentation of visual stimuli, Green (1984) found that a reduction in the response processing demands from a choice RT to a go-no-go response reduced the intrahemispheric task processing demands. In fact, no interference was evident between task processing and response processing when the go-no-go response was used. It is possible that a more complex motor response would have resulted in significant hand differences in the present study. Wickens & Sandry (1982) found that integrity of hand assignment resulted in hand differences on a combined verbal/spatial task paradigm in which the response to the verbal task was also a button push. In their study, however, subjects performed a choice RT task and were required to make response on two different buttons.

One additional set of analyses was performed on the dichotic listening data which did lend some support to the notion that hand of task performance is related to performance. These analyses addressed the predictability of the REA. It was hypothesized that the size of the REA could be predicted by a knowledge of scores on a number of factors including sex, degree of handedness, hand used to perform the DL task and ear of primary telephone conversation. In addition, for the DL scores obtained during the dual task trials, it was hypothesized that performance on the concurrent spatial task might also predict the size of the REA. The rationale behind this was that, during the dual task trials, if the individual was focusing greater attention on the concurrent spatial task, this would be reflected in better performance scores on the spatial task. It might also be reflected in larger REAs due to the fact that the right hemisphere would be more heavily engaged in spatial processing, and thus, have little "spare capacity" left to process and transfer left ear auditory inputs (resulting in slower RTs to left ear stimuli). These analyses did not reveal a great deal. However, they did suggest that hand of task performance does predict the REA in some cases. For the DL task alone, sex and hand of DL task performance accounted for a total of 12.8% of the experimental variance, and for the DL task during concurrent performance of the DM task, hand of task performance accounted for 5.3% of the variance. Unfortunately, there was a severe restriction in range for several of the predictor variables, thus contributing to the lack of prediction of REA. However, it was interesting to note that hand of task performance did account for a significant proportion of the variance in DL task performance, even though this was not significant across tasks.

Spatial Task Performance

Often the hemisphere required for task processing is inferred from the relative performance of the two hands or from the degree to which a concurrent verbal task (known to invoke left hemisphere processing) interferes with performance on an ostensibly "spatial" task. From the present findings, it was again difficult to infer with certainty, that the right hemispheric processing resources were invoked by the three "spatial" tasks. There were two findings which supported the notion of right hemisphere processing. However, there was one additional finding which contradicted this notion. Thus, performance on the spatial tasks was only somewhat consistent with many of the previous findings that the right hemisphere is more proficient at processing visuospatial information than is the left (e.g., Cohen, 1973; Patterson & Bradshaw, 1975). Also of interest was the fact that sex differences were found on two of the three spatial tasks. Performance on each spatial task --

as an independent task and as it relates to performance on the DL task -- will be discussed first. Following this, a comparison summary of the three spatial tasks will be presented.

Display Monitoring Task

Three measures of performance -- RT, number of correct signal discriminations (hits), and number of missed signals (misses) -- were recorded for this task. Reaction time was found to be relatively insensitive to variations in sex, hand, or task load. This was not surprising, however, and was most likely attributable to the nature of the task and to the experimental instructions. First, the nature of the task was such that subjects were required to scan two ongoing visual displays and to respond when they noticed a bias in the ongoing movement. The RT was recorded not as a measure of simple RT to a stimulus, but rather, as a measure of the amount of time to discriminate a change in stimulus conditions. Since this time was much longer than a simple RT measure, it was less affected by small differences which may have been present due to sex, hand, or task load. Furthermore, since there was a total of ten signals, the maximum number of responses that could be made was ten. However, most subjects missed several signals, reducing the number of responses contributing to the average RT.

Although the median RT was used to minimize the potential for bias due to extreme scores, the small number of responses may still have contributed to the lack of variability in RTs. In addition, experimental instructions may also have played a part in the lack of significance in RT. Subjects were instructed to respond as soon as they detected a biased signal, but were cautioned to avoid making a response until they were absolutely sure that a biased signal was present, because responses made to nonexistent signals would be scored against them. This may have resulted in conservative responding, and may have caused the RT scores to be slightly lengthened and clustered, with little variability.

An analysis of variance performed on the number of signal hits indicated that the number of hits was significantly different across hands, with the right hand outperforming the left hand. This is partially consistent with the notion of task-hemispheric integrity. That is, the task-hemispheric integrity hypothesis suggests that during single task performance, the hand ipsilateral to the hemisphere of task processing (in this case the right hand) will be more proficient because processing demands are distributed across hemispheres. For the present task, this was the case. However, the right hand outperformed the left in both single and dual task trials, and improved performance with integrity of task processing demands (i.e., hemisphere of task processing, response hand) was not evident in the dual task condition. Perhaps with more complex motor response requirements on the DM task, improved performance with the integrity hand assignment would have been seen during the dual task trial. As was suggested earlier, it is also possible that the executive processing required by the DM task (i.e., synthesis of information over time, decision-making) which is hypothesized to be under left hemisphere control, may have actually activated left hemisphere resources so as to facilitate right hand performance. One final explanation for the better right hand performance may have been the fact that all subjects were right-handed. However, since this right hand proficiency was not found across tasks (and was not seen on the UT task which required more coordinated motor movements), hand differences on the number of hits is unlikely to be attributable to subjects' handedness.

For the number of misses on the DM task, there was a significant hand x task interaction. This interaction was not consistent with the main hand effect for number of hits, but does support the notion of improved performance with hemispheric integrity. Interestingly, during single task performance, there was no difference in the number of misses made with the right hand as compared to the left. During concurrent performance with the verbal auditory task (i.e., left hemisphere), however, the number of misses made by the left hand (i.e., right hemisphere) did not increase over single task levels while the number of misses made by the right hand (i.e., left hemisphere) significantly increased. It appears that when the processing resources of the left hemisphere were occupied with the concurrent verbal task, there were fewer resources available to instruct the right hand to respond to spatial dial signals. In fact, the number of misses made by the right hand during dual task performance nearly doubled, while those made by the left hand actually decreased, although this decrease was not significant. This finding supports the task-hemispheric integrity hypothesis. Thus, for the DM task, the number of signal misses during concurrent performance of a verbal task is minimized by maintaining integrity between the hypothesized predominant hemisphere of task processing (i.e., right hemisphere) and the response hand (i.e., left hand).

Taken as a whole, the performance on the DM task appeared to be only moderately affected by the concurrent auditory task. Interestingly, this task was the one which interfered with performance on the auditory task to the greatest degree. The nature of the DM task was such that it imposed a heavy sensory/perceptual demand on the subjects, requiring continuous input of rapidly changing visual stimuli. It is probable that, for the reasons cited above, there was little variability in the scores for this task, and thus, little effect of the concurrent auditory task was reflected in the performance measures. However, because of the specific input resource demands imposed by this task, it was likely that subjects had a difficult time focusing their attention on the rapid input and processing of the two channels of information being presented simultaneously to them.

Spatial Processing Task

Findings from the SP task did not altogether support the hypothesis that integrity of hemisphere of information input, central processing and response will optimize performance. There were no significant effects for hand of task performance or task load for RT, number of hits or number of misses. This finding was unexpected in light of the fact that the SP task was designed to impose heavy central processing demands on the subjects, and was thus hypothesized to result in strong task-hemispheric integrity effects. However, taken in combination with the results of the concurrent DL task, some evidence of more proficient performance with task-hemispheric integrity assignments was evident. The greater proficiency with integrity assignments was actually manifest on the auditory task but not on the spatial task. That is, during concurrent performance of the SP task, the number of auditory target misses to information presented in the left ear (i.e., right hemisphere) was significantly greater than the number of misses to right ear targets. From this finding it is inferred that the SP task definitely invoked right hemisphere processing resources and suggests the possibility that, during certain types of concurrent task demands (i.e., central processing requirements), verbal auditory information is processed more proficiently when presented to the right ear than to the left. Although not presented ipsilaterally, it appeared that SP task performance was not likewise affected by maintaining hemispheric integrity between the primary processing hemisphere (i.e., right hemisphere) and response hand (i.e., left hand).

Interestingly, the only significant differences found on this task were between males and females. Males made more hits and fewer misses than females did. Research support for sex differences in spatial performance is equivocal and has been the topic of much controversy in the field (cf. Caplan, MacPherson & Tobin, 1985 for review). However, the results here are consistent with the findings of a recent meta-analysis by Linn & Petersen (1985), who found large homogeneous effects for sex on the Vandenberg test of mental rotation (Vandenberg, 1971), and moderate, fairly homogeneous sex effects on the PMA space test of mental rotation (Thurstone & Thurstone, 1941). Since the SP task used in the present study also required mental rotation, these results are consistent with other research findings. Linn and Petersen propose a number of reasons why these sex differences may occur, including a differential rate of mental rotation, differential efficiency in the application of rotation strategies, differential use of analytic processes, and differential caution in responding. As this was not the main focus of the present study, it is uncertain as to which of these factors, if any, caused the gender differences on the SP task. However, based on informal subjects' comments regarding the task, the differences seem likely to have resulted from differential application of rotation strategies or from differential use of analytic processes.

Unstable Tracking Task

For the deviation performance data (RMS error), subjects performed more proficiently in the single task condition than they did while performing the UT task concurrently with the DL task. This deterioration in performance between single and dual task conditions was seen only on the UT task -- with the exception of signal misses on the DM task, there were no differences between single and dual task performance on either the DM or SP task. This result may have been due to the nature of the responses required for each of these tasks and the relative facility with which these can be performed concurrently. Specifically, the auditory task and the two other spatial tasks (DM and SP) each required discrete responses to stimuli, while the UT task required subjects to make continuous responses. Evidence from other studies (e.g., McLeod, 1977; Wickens, Sandry & Vidulich, 1983) suggests that discrete manual responses with the nontracking hand interfere with the continuous tracking response. In addition, it has been shown that tasks which require different timing sequences (e.g., Peters, 1977) or different control dynamics (e.g., Chernikoff, Duey & Taylor, 1960) are difficult to perform concurrently. It is possible then, that the discrete button push response required for the auditory task interfered with tracking performance but did not interfere with the discrete button push responses required for the other two spatial tasks.

Sex differences were found for both the deviation scores and the number of edge violations, with males outperforming females in both areas. Of interest was the fact that, for number of edge violations, males' performance improved from single to dual task trials, whereas females' performance deteriorated. Previous research (Kuechenmeister, Linton, Mueller & White, 1977) has found that females, in general, show slower rates of eye tracking than males, perhaps accounting for the differences in performance. However, because there were no sex differences found on the DM task which involved similar visual scanning demands, the poorer rate of tracking is not likely to have resulted from these sex differences in scanning rate. A more likely explanation may rest in the amount of prior related experience. The tracking task shares features similar to video games, and it is speculated that males tend to play more video games than females. Perhaps males' experience in this similar domain may have facilitated their performance on the tracking task. Unfortunately, no information was gathered on video game experience. Therefore, previous related experience can only be speculated as a potential cause for the sex differences.

Comparison of Spatial Tasks

The three spatial tasks had a differential effect on the concurrent performance of the auditory verbal task, although it appeared that the DL task had a relatively small reciprocal effect on the performance of the three spatial tasks. It is interesting to note that the DM and SP tasks, which loaded primarily on the input and central processing stages of information processing respectively, each had a detrimental effect on the concurrent auditory task. Of these two, the DM task caused the largest overall decrements in performance on the DL task. However, this may also be attributable to the fact that the DM task may have invoked a substantial amount of left hemisphere processing resources in addition to the speculated right hemisphere resources, thus affecting auditory task performance bilaterally. It would be interesting to assess hemispheric processing by some independent means, in order to determine whether this was the case. Physiological indexes such as regional cortical blood flow (Knopman, Rubens, Klassen & Meyer, 1982; Maximillian, 1982) and (although still somewhat speculative) multiple site recording of EEGs (Doyle, Ornstein & Galin, 1974; Gevins, Doyle, Cutillo, Schaffer, Lannehill, Ghannam, Gilcrease & Yeager, 1981) have been used to demonstrate hemispheric activation. If the DM task were invoking both hemispheres to a substantial degree, this might be made evident when using one of these techniques. In terms of the number of right hand misses, the DM task was reciprocally affected by the auditory task. That is, when the DM task was performed concurrently with the left hemisphere-invoking auditory task, the number of DM misses made by the right hand (left hemisphere) was greater than those made by the left hand -- the hand which was thought to be controlled by the primary hemisphere of task processing (i.e., right). Although the SP task caused decrements in performance on the auditory task, it appeared that performance of the concurrent auditory task did not affect performance on the SP task. The UT task, on the other hand, facilitated performance on the concurrent auditory task. However, the auditory task resulted in small, but significant, reductions in performance on the concurrent UT task.

Perhaps even more interesting than this was the fact that sex differences were evident in performance on two of the three spatial tasks. Based on cognitive perspective, Linn & Petersen (1985) have divided spatial tasks into three categories -- spatial perception, mental rotation and spatial visualization. The SP task in the present experiment is easily placed into the mental rotation category. However, the other two tasks used in the present experiment are less easily categorized but seem to best fall into the spatial visualization category. As was noted previously, sex differences are fairly consistent in mental rotation. These were manifested in the present study in the sex differences on the SP task. However, sex differences in spatial visualization have been found to be quite small and are relatively inconsistent. This, and the lack of sensitivity of the performance measures on the DM task, probably accounts for the lack of differences between males and females on this task. Rather sizeable gender differences were seen on the UT task. It is uncertain whether these differences actually reflect some inherent difference in spatial processing ability, or whether they are the result of differential experience levels.

Theoretical Implications

The present findings seem to offer only partial support to the claims of the two processing models (i.e., task-hemispheric integrity, hemispheres of processing), while failing to support some of their assumptions. The task-hemispheric integrity hypothesis predicts that performance in a dual task situation will be facilitated if the hand of task performance maintains "integrity" with the hemisphere of task processing. This hypothesis was only partially substantiated by the results of the present study. The ear of auditory stimulus input did affect stimulus processing -- inputs to the right ear were responded to more quickly than inputs to the left ear. Since the auditory inputs were verbal in nature, this REA does support the notion that input of information directly to hemisphere of processing will facilitate performance. Also, for the SP task which invoked a heavy central processing load in the spatial domain, the number of missed auditory target stimuli was minimized when information was presented to the right ear as compared to the left.

In general, there was no difference based on hand of task performance. This was true for the DL task and for two of the three spatial tasks. The only hand differences that were found were on the DM task for number of signal hits and number of missed signals. The finding for signal hits offered only partial support for the task-hemispheric integrity hypothesis as this effect did not interact with hand. However, the nature of the result for signal misses did support the predictions of the task-hemispheric integrity hypothesis. That is, fewer misses were made on the spatial task with the left hand than with the right during concurrent performance of a verbal task.

As was suggested earlier, it is possible that the inability to present <u>completely</u> lateralized auditory information may have reduced the hand effect. Any slight right hemisphere "priming" which may have occurred due to ipsilateral auditory stimulus access (for right ear inputs) or due to contralateral access (for left ear inputs) may have served to activate that hemisphere sufficiently to facilitate left hand motor responses. It is also possible that the simple response requirements of the task (i.e., go-no-go button push) did not impose heavy organizational motor output demands and thus, did not result in hand differences.

In considering the way in which the data relate to the hemispheres of processing approach, again they offer only partial support for the model. One of the basic assumptions of this model is that the two hemispheres have control over qualitatively different resources which cannot be made available to the other hemisphere, no matter how beneficial it would be to performance. Based on differential patterns of interference of concurrent verbal and spatial tasks (e.g., Baddeley & Lieberman, 1980; Wickens, Mountford & Schreiner, 1981; Wickens & Sandry, 1982), and on differential effects on motor task performance (e.g., Carnahan, Elliott & Lee, 1986; Hicks, 1975; Ikeda, 1987), it is believed that the processes involved in tracking are primarily right hemisphere processes. The fact that the UT task facilitated performance on the DL task seems to counter the prediction that hemispheric resources cannot be shared. During the concurrent auditory/tracking task trial, it would appear that right hemisphere resources that were not available during the single task condition were made available for task processing and were somehow "shared" with those of the left hemisphere in order to facilitate performance on the auditory task. If additional right hemisphere resources were not shared for processing the DL task, it would be difficult to explain the way in which auditory task performance improved during concurrent performance of the spatial UT task.

Apart from this, the fact that the verbal task interfered little in spatial task performance suggests that the tasks invoked somewhat independent processing resources, and that there exists separate pools of resources which may be located within the hemispheres for use to perform these different types of tasks. That is, spatial task performance was relatively unaffected by the additional processing demands of the concurrent left hemisphere auditory task, even when the auditory task required some right hemisphere processing resources to transfer verbal information to the left hemisphere. This finding would seem to offer partial support for the hemispheres of processing claim that the hemispheres are independent. However, as is noted by Friedman and her colleagues, in order to completely determine the hemispheric processing requirements of tasks, a task emphasis methodology must be employed and trade-offs between the two tasks must be found. The reasoning for this is as follows: If two tasks require resources of the same hemisphere, then when they are performed simultaneously they should interfere with each other. Requiring subjects to emphasize one task (through performance incentives) should result in deterioration in performance on the other task and vice versa. However, if two tasks do not share overlapping resources, then changes in performance emphasis should not cause trade-offs in performance. Since an equal emphasis was placed on both tasks in the present study, it cannot be said for certain whether the tasks did indeed require separate hemispheric resources.

Implications for Future Research

The present paradigm does seem to offer the potential for categorizing different tasks in terms of the kinds of hemispheric resources they require. This information could be useful in deciding what types of tasks can (or should not) be performed concurrently. For example, in the present study three tasks, ostensibly all spatial in nature but differing in the kind of spatial processing required, had differential effects on a concurrent verbal task presented auditorially. It would be interesting, and potentially useful, to combine the verbal auditory task with various other tasks, ostensibly verbal in nature, to determine the effects of each of these tasks on the auditory task performance. Based on the results, it may be possible to categorize tasks in terms of the hemispheric resources required to perform them. This could offer insight into the kinds of tasks that can be efficiently time-shared, and might offer guidelines for system designers regarding more proficient ways of presenting concurrent verbal and spatial information.

In addition, previous studies have demonstrated a left ear advantage (LEA), although not as consistent as the REA, for tones (e.g., Goodglass & Galderon, 1977; Ley & Bryden, 1982). Given the fact that system designers must often decide whether to present auditory information as verbal instructions or as tones, it would be interesting to replicate the present study with verbal and spatial tasks while using dichotically presented tones rather than words. If different results were found, this would further substantiate existing knowledge of the hemispheres required for processing of various tasks. Taken together, this information could clarify the concern about the amounts and kinds of information that the human operator can successfully process at any given time. Also, as was demonstrated by the present study, performance of certain kinds of tasks may actually facilitate performance on a concurrent auditory task. While it is acknowledged that this result was found in a laboratory setting, replication in an applied setting would certainly offer tremendous human factors potential for task and system design in such areas as aircraft information presentation and flight control management.

One final area of research which should be explored relates to the hemispheres of processing approach. As Friedman and her colleagues suggest (cf. Polson & Friedman, 1988), in order to determine definitively, the hemisphere required for task processing, a task-emphasis methodology must be used and tradeoffs in performance between tasks alleged to invoke the same hemisphere, must be demonstrated. It would be interesting to perform the above studies, altering the emphasis between the auditory and visual tasks, to determine whether task emphasis affects their relative performance.

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Appendix A

Annett Handedness Questionnaire

PROBABILITY MONITORING TASK

In this task you will be monitoring two displays which are intended to have the appearance of rectangular electromechanical dials like those on a machine. The dials consist of six pointer positions and a pointer which appears below the positions and moves across the dial from one position to another. Under normal conditions, the pattern of pointer movement is random. This means that the pointer is equally likely to move from any position to any other position. Periodically, the pointer movement on one of the dials will become nonrandom, such that the pointer will tend to stay on one side of the dial more than the other. This is known as a "biased signal." During a biased signal, 95% of the pointer movements will be on one side of the dial, and only 5% will be on the other side. Your task is to scan back and forth between the two dials and watch carefully for nonrandom or "biased" patterns of pointer movement. If you think you see a biased signal on either dial, press the button that corresponds to the dial (right button for the right dial, left button for the left dial). When you correctly respond to a signal, it will be eliminated, and the pointer will go back to moving randomly again.

Monitoring periods last 3 minutes each. You will start each monitoring period with your left (right) hand resting on the box between the two buttons. Keep your hand in this position at all times during the task. When I tell you to do so, you may start the task by pressing either of the two buttons. During each 3-minute period, you can expect to see approximately 10 signals. If you do not respond immediately, the signal will remain for 12 seconds. Two signals will never appear on different dials at the same time. Try to avoid responding until you are sure that a signal is present because responses to nonexistent signals will be scored against you. The screen will be turned off at the end of each monitoring period. At this time, please wait for my instructions for your next task. Do you have any questions?

SPATIAL PROCESSING TASK

In the spatial processing task, pairs of bar graphs, or histograms, will be presented to you one at a time. Your task is to memorize the shape of the first histogram in each pair and then decide whether the second histogram is the same shape or a different shape. You may indicate "same" and "different" responses by pressing the left and right buttons on the box (left button for same, right button for different). There will be four bars in each histogram. The first histogram will always be presented in an upright position. However, the second histogram in each pair will appear rotated on its side (90 degrees), either to the left or to the right.

You will begin the task with your left (right) hand resting in a neutral position between the two buttons on the box. Please keep your hand in this position throughout the task. You control the start of the task by pressing either of the two buttons. When the first histogram appears on the screen, memorize the shape and then respond "same" or "different" to the second. The first histogram will stay on the screen for a specified amount of time and then will go off automatically. However, the second histogram will stay on the screen until you make a response (up to a maximum amount of time) -- your response will erase the second histogram, and then the next pair of histograms will start. Try to respond as quickly and accurately as possible. Respond as quickly as you can, but if you start making errors because you are rushing your decision, slow down. Each trial will last for a period of 3 minutes. At the end of each trial, the screen will be turned off. At this time, please wait for instructions regarding your next task. Do you have any questions?

UNSTABLE TRACKING TASK

The object of the unstable tracking task is to keep a cursor centered over a target area in the middle of the screen. You control the movement of the cursor by turning the control knob with your left (right) hand. Rotating the knob to the right (clockwise) moves the cursor to the right, and rotating it left (counterclockwise) moves the cursor to the left. At the start of the task, the cursor will appear at the center of the screen and will naturally tend to move away from the center. Again, your task is to try to keep the cursor centered between the target at all times. If the cursor reaches the edge of the screen, it will reappear at the center target and begin moving away again. This is called a control loss, and will be scored against you.

Each trial will last for a period of 3 minutes. You control the start of the task by turning the knob away from zero and then back to zero. The cursor is very sensitive to the input that you give it. Very small movements on your part will cause the cursor to move a great deal. Therefore, use very small adjustments to keep the cursor centered. When the task is over, the screen will be turned off. At this time, please wait for instructions regarding your next task. Do you have any questions?

DICHOTIC LISTENING TASK

The object of this task is to respond as quickly as possible by pressing the red button when you hear the target word "dog." Please hold the button in your right (left) hand with you thumb over the button, and rest your arm in a comfortable position, either on the armrest of the chair or in your lap. In a moment, you will hear a series of one-syllable words presented to you over a set of headphones. During the series, different words will be presented simultaneously to your left and right ears. Try to focus your attention equally on the words in both ears. Listen for the target word "dog." When you hear it in either ear, respond as quickly as you can by pressing the red button. Release the button immediately and listen again for the next presentation of the target word. The target word is equally likely to be presented in either ear. Each trial of the dichotic listening task will last for a period of 3 minutes. At the end of the tape, please wait for instructions regarding your next task. Do you have any questions?

Autobiographical Statement

Paula Guerette was born in Manchester, CT on April 21, 1962. She studied general psychology at Georgetwon University, Washington, D.C. where she received a Bachelor of Science degree in 1984. Following this, Ms. Guerette worked as a research assistant at the Advanced Research Resources Organization in Bethesda, MD. There she was involved in consulting work with the government and the private sector, primarily in the development and validation of employee selection batteries for physically demanding jobs. In 1985, she entered graduate school at Old Dominion University, Norfolk, VA, and received a Master of Science degree in general psychology in 1987. Ms. Guerette continued her graduate studies at Old Dominion University, and will receive a Doctorate of Philosophy in Industrial/Organizational psychology with an emphasis in Engineering and Systems psychology in 1989. She recently completed an internship at the McDonnell-Douglas Corporation, Long Beach, CA, where she explored the cognitive processes involved in aircraft flight operations, and the relationships between these and pilot performance. She has also been involved in research on team training, conducted for the Navy, and on the influence of the brain hemispheres on human performance, conducted for NASA. In 1987, Ms. Guerette received the Thomas K. Dempsey Memorial Award for student research in the field of Human Factors. She is also a member of the honor societies of Phi Kappa Phi and Psi Chi. Her publications are listed on the next page.

PUBLICATIONS

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