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Hemispheric Effects of Verbal Information Processing on Single and Dual Task Performance

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ABSTRACT

HEMISPHERIC EFFECTS OF VERBAL INFORMATION PROCESSING
ON SINGLE AND DUAL TASK PERFORMANCE

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Several theories have been proposed to predict performance when operators time share tasks. The Hemispheres as Resources Model suggests tasks will be performed efficiently together if each hemisphere allocates resources to one task. The Task Hemispheric Integrity Principle predicts the best dual task performance will be found when the shortest processing route is maintained. The purpose of the present study was to test the single and dual task performance predictions of these two models. The concurrent performance of two verbal tasks was used to compare the importance of ear of attention, hemisphere of processing, response hand and gender on task performance. Sixty-four subjects (32 males, 32 females) completed single and dual task trials of three verbal tasks: a dichotic listening task, an antonym match task and a continuous recall task.

The results of the present study provide mixed support for the Hemispheres as Resources Model and the Task

Hemispheric Integrity Principle. There were gender differences in performance which indicate males are more lateralized for hemispheric functioning than females. The findings of the present study are discussed in terms of the theoretical implications and the implications for future research.

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INTRODUCTION

Information Processing

In today's increasingly complex work environments, it is important to understand how individuals obtain, process and use information to complete job assignments. Automation of jobs and the addition of computers in the work place have facilitated the presentation of large amounts of information to the user. However, individuals have very limited resources for processing quantities of information as compared to computers. Several areas of research are attempting to understand the strengths and limitations of people as information processors. Designers can use the knowledge from this research to design work stations that present information to the operators in a "friendly" manner.

One area of research has been concerned with the ability of workers to perform efficiently two tasks at the same time. Several theories have been proposed to account for the degree to which two tasks can be performed as efficiently together as they can be performed in isolation. The hypothetical construct of mental resources has been used to explain and predict performance during concurrent tasks.

Single Resource Models

Single resource models, such as Kahneman's model (1973), hypothesized the existence of one undifferentiated pool of resources that is available for information processing. A resource has been defined as "any internal input essential for processing that is available in quantities that are limited at any point in time." (Navon, 1984, p. 217) These resources are allocated to complete the information processing demands of a task. At any one time, the pool of resources is limited in its capacity. Single resource models describe decrements in performance as due to a lack of available processing resources. The level of task performance depends on the 1) resources required by the task and 2) the resources that are available. When two tasks are performed simultaneously, this model predicts that all tasks compete with one another for processing resources. Tasks will interfere with one another to the extent that they require resources from the single resource pool.

However, there are several phenomena observed in dual task research that are difficult for single-resource theories to explain: difficulty insensitivity, perfect time-sharing, and difficulty-structure uncoupling (Wickens, 1984). Several researchers have found that some tasks performed simultaneously result in performance decrements while other tasks result in almost no decrements in performance. Several examples of difficulty insensitivity have been found where increases in the difficulty of one task fail to affect the performance of the simultaneous task. Some time sharing studies found subjects could maintain the same level of performance whether tasks were performed independently or simultaneously (Allport, Antonis and Reynolds, 1972; Shaffer, 1975; Wickens, 1976). One example of perfect time-sharing was a study that asked subjects to sight-read music and perform an auditory shadowing task at the same time (Allport et al., 1972). Researchers have also found examples of difficulty-structure uncoupling in which "the more difficult of two tasks when paired with a third task actually interferes less with the third task than does the easier of the two tasks when it is paired with the third task" (Wickens, 1984, p.77).

The above experimental findings do not directly support the central assumption of the single resource models which state that there is an undifferentiated pool of resources for which all tasks compete. The results of this research led to the idea that there are multiple pools of resources which can be used for the information processing requirements of one or more tasks (Navon and Gopher, 1979). Multiple resource models grew out of the lack of single resource models to account fully for the results of dual task research.

Multiple Resource Models

In contrast to the single capacity models, the multiple resource models suggest that there are several processing mechanisms each of which requires it own pool of resources (Navon and Gopher, 1979; 1980; Isreal, Chesney, Wickens and

Donchin, 1980; Wickens, 1980; Friedman and Polson, 1981). One mechanism can allocate its resources to one or more tasks. Task performance depends on 1) the amount and type of resources that the task requires and 2) the amount and type of resources that are available.

Multiple resource models account for the dual task research findings which presented difficulties to single resource models. In dual task situations, multiple resource models predict that decrements from single to dual task performance may occur when tasks compete for the same resource pools, while no decrements may occur when tasks require different resources. Perfect time sharing may occur if tasks require separate resources. Difficulty-structure uncoupling can occur when two tasks that make heavy resource demands on separate sources are compared to two tasks that place moderate demands on the same resource pool. Multiple resources also provide an explanation for the phenomenon of difficulty insensitivity. Increases in the difficulty of one task will require more resources. Decrements in performance of the other task will be observed if the tasks require similar resources while no decrements (difficulty insensitivity) will occur if the tasks rely on separate resources.

An important feature of the multiple resource theories is the nature of the resources. Navon and Gopher (1979) proposed the idea of multiple resources and later postulated that there were at least two independent types of resources (Gopher, Brickner and Navon, 1982). Research with typing tasks suggested there was one type of resource associated with motor processes and one associated with perceptual processes (Gopher, Brickner and Navon, 1982). These articles do not address in detail the nature of the resources or the relationship between various resources. However, Wickens (1980) and Friedmen and Polson (1981) have developed models that specifically address these issues. Wickens (1984) has proposed a model in which resources can vary on three dimensions: stages of processing, codes of perceptual and central processing, and modalities of input and response. Friedman and Polson (1981) have set forth a theoretical framework which views the cerebral hemispheres as two processing resources. The following sections will discuss in more detail the ideas and research devoted to multiple resource theories of Wickens (1980) and Friedman and Polson (1981).

Wickens' Resource Model

Based upon a review of previous dual task literature, Wickens (1980) proposed a multiple resource model in which resources can be defined by three dimensions. By definition, each of these dimensions is divided into two separate resources, 1) stage of processing (early versus late processing stages), 2) modalities of input and response (auditory versus visual processing modalities), and 3) codes of perceptual and central processing (verbal versus spatial processing codes). The model predicts tasks will interfere with each other to the degree that they require common resources. Each of the dimensions of this model are discussed in the following paragraphs.

In the stages of processing dimension, Wickens hypothesizes that the early stages of processing, namely perceptual and central processing, require the same resources. The resource pool for perceptual and central processing is functionally separate from the resources used for response processes or the late stage of processing. This hypothesis has support from experiments which find that tasks which require mostly perceptual encoding processing resources can be efficiently time-shared with tasks that require mostly response processing (Wickens, 1976; Wickens and Kessel, 1980) but not with other perceptual encoding tasks. In addition, manipulating the task demands of one stage of processing has only small effects on task which rely heavily on the other processing stage (Isreal, Wickens, Chesney and Donchin, 1980).

The dimension of modalities of input and response suggests that at the input stage, visual and auditory tasks depend on different resources; moreover, at the response stage manual responses require different resources from verbal responses. Therefore, an auditory and a visual task will be performed more efficiently than two visual tasks. Several dual task studies have found an advantage for the concurrent performance of tasks that offer cross modal information presentation (auditory/visual) as opposed to intramodal presentation (visual/visual) (Treismen and Davies, 1973; Wickens, 1980). Recently, Wickens and Liu (1988) have suggested that the inferior performance of intramodal tasks is not due to competition for central processing resources but in the visual scanning costs associated with performing two visual tasks. No superiority is found for cross modal tasks when the scanning costs of intramodal visual tasks are removed (Wickens, Sandry and Vidulich, 1983; Tsang and Wickens, 1988).

The final dimension, codes of perceptual and central processing, proposes that verbal and spatial processing represent two functionally separate resources. The prediction that tasks which utilize the same processing codes will be less efficiently time-shared than those task which use different processing codes is supported by several lines of research (Kinsbourne and Hicks, 1978; Baddeley and Lieberman, 1980; Friedman, Polson and Dafoe, 1988; Wickens and Liu, 1988).

The dimension of verbal and spatial codes has relevance to three stages of information processing: perceptual encoding, central processing and response processing. At the perceptual stage, verbal tasks will activate different resources than tasks which are spatial in nature. Spatial and verbal codes are also important in central processing and working memory where researchers have identified a spatial and a verbal working memory system (Braddeley and Lieberman, 1980; Wickens and Sandry, 1982; Klapp and Netick, 1988). This dimension is also reflected in response processing, the last stage of information processing, where the verbal code is represented by vocal responses and the spatial code is represented by manual responses. The model predicts that to maximize performance at all three stages of information processing with verbal and spatial codes, tasks should rely on the separate verbal and spatial resources.

Task-Hemispheric Integrity Principle

In addition to being defined functionally, there is evidence that spatial and verbal resources may be structurally separate. Kinsbourne and Hicks (1978) suggested that these resources are anatomically related to the right (spatial) and left (verbal) cerebral hemispheres. Moscovitch (1976) found the right hemisphere to be superior in the performance of spatial tasks while the left hemisphere was superior for verbal tasks.

The evidence from studies looking at the structural differences between verbal and spatial abilities led Wickens to formulate the task hemispheric integrity principle. The task-hemispheric integrity principle states that superior performance will be found when task configurations maintain the shortest processing path from input of a stimulus to the response. This principle is intended to be used by system designers in planning the physical layout of operator workstations. This principle makes specific recommendations about the placement of verbal and spatial tasks.

The task-hemispheric principle is based on several assumptions. The first premise supposes that visual information is first projected to the contralateral hemisphere. For example, information presented in the left visual field is transmitted to the right cerebral hemisphere while the left hemisphere first receives information from the right visual field (see Figure 1). The task-hemispheric integrity principle also assumes the two hemispheres represent separate processing resources relatively dedicated to either verbal (left hemisphere) or spatial (right hemisphere) processing. The final premise contends that the hemispheres have contralateral control of the limbs (Lawrence and Kuypers, 1968; Brinkman and Kuypers, 1972). Therefore, the right hemisphere directs the responses of the left hand while the left hemisphere controls the responses of the right hand (see Figure 1).

The task-hemispheric integrity principle suggests that superior performance will be found with task configurations in which the hemisphere that is mostly responsible for the central processing of a task, directly receives the input and controls the response. To maintain this principle, a

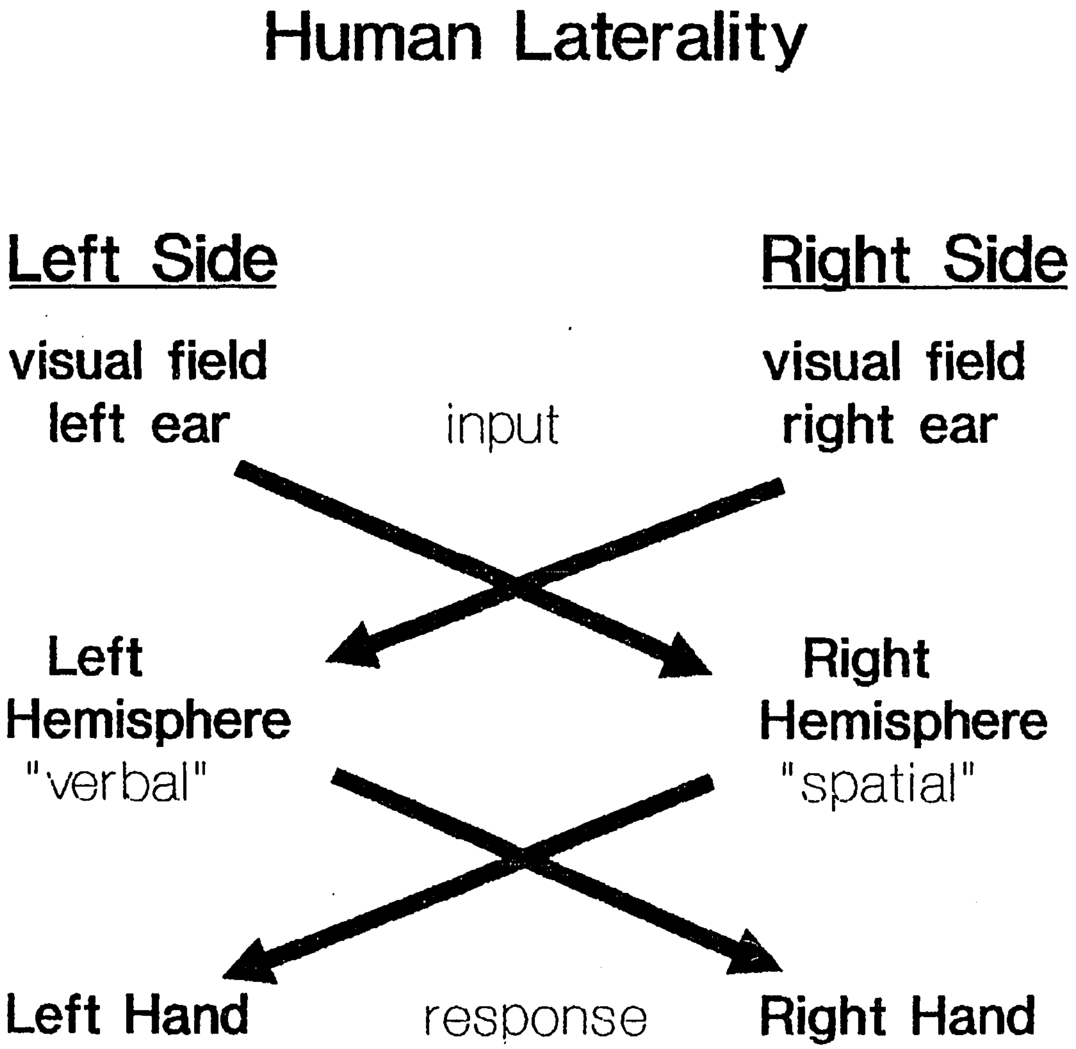


Figure 1. The path of stimulus processing in the two sides of the body from perceptual input, to hemisphere of processing, to hand of response.

verbal task should be presented to the right visual field and responses should be made with the right hand. Likewise, task-hemispheric integrity indicates that a spatial task should be presented to the left visual field and controlled by the left hand.

An advantage for task hemispheric intergrity will not be seen for single task performance since the hemispheres rapidly exchange information via the corpus callosum (Wickens, Mountford and Schreiner, 1981). An advantage for integrity may only be seen in dual task situations in which each of the hemispheres is heavily engaged in the completion of a task. Later, Carswell and Wickens (1985) suggested that there may be performance differences between the hands during single task trials, but the task hemispheric integrity principle is not applicable to single task situations. The principle only describes superior performance of task configurations in dual task situations (Carswell and Wickens, 1985).

Research on the Task-Hemispheric Integrity Principle

Research has found mixed support for the task-hemispheric integrity principle. Wickens, Mountford and Schreiner (1981) compared the integrity and nonintegrity configurations for a spatial tracking task paired with a verbal auditory (monaural) memory task and for the tracking task time-shared with a visual verbal classification task (both presented foveally). In general, they found better performance in the integrity conditions where the left hand completed the tracking task and the right hand responded to the verbal task. A second study by Wickens, Vidulich and Sandry-Garza (1984) also found superior performance with the compatible layout in which the task presentations were either shown to the right or left of the subject's midline. Other studies have found no advantage for task-hemispheric integrity when the degree of visual separation between two visual tasks is reduced (Wickens and Sandry, 1982; Carswell and Wickens, 1985) or when one hand controls the responses to both tasks (Carswell and Wickens, 1985).

Most of the experiments investigating the task-hemispheric integrity principle have used visually presented tasks. There are often instances in which operators must time-share tasks with visual and auditory information presentation. The task hemispheric principle can be applied to auditory tasks although it was only proposed for visual tasks. The use of an auditory task to present lateralized information is reviewed in the dichotic listening section.

Hemispheres as Resources

Another approach to multiple resources was presented by Friedman and Polson (1981) who view the two cerebral hemispheres as independent resource systems. The hemisphere in which the task processing takes place is most important in determining and understanding how tasks interact in dual task situations. Therefore, tasks which use resources of the same hemisphere will result in greater interference than tasks that rely on different hemispheres (Polson and Friedman, 1988).

The hemispheres as resources model is based on three theoretical assumptions. The first assumption is that each hemisphere has control over resources which are qualitatively different from the resources of the other hemisphere. In addition, the resources of each hemisphere are distinct and these resources cannot be "shared" between the hemispheres. Two studies have used a lateralized verbal task presented visually and found results which support the concept of the hemispheres as distinct resources (Friedman, Polson, Dafoe and Gaskill, 1982; Herdman and Friedman, 1985).

Evidence that the hemispheres have different resources has been investigated using laterally presented auditory information in dual task situations. Hellige and Wong (1983) tested hemispheric specific interference using dichotically presented syllables with either a concurrent memory load or no concurrent memory load. They found that a memory load of six words reduced the recognition of right ear stimuli but not the recognition of left ear target. Right ear stimuli are processed by the left hemisphere and the verbal memory load is also rehearsed by the left hemisphere. Performance was poorer when both of the tasks required processing by the left hemisphere. However performance improved when responding to left ear stimuli which indicates the right hemisphere was allocated to the dichotic listening task while the left hemisphere processed the memory load task. These results support the concept that the two cerebral hemispheres have separate processing capacities. A similar pattern of results has been found in studies using visual laterality tasks that require verbal processing and concurrent verbal memory tasks (Hellige and Cox, 1976; Hellige, 1978; Hellige, Cox, and Litvac, 1979; Friedman et al., 1982).

The second theoretical assumption is that both hemispheres can complete the information processing requirements of most tasks using their own respective resources. This is contrary to Wicken's Model which assumes that information that is incompatible with a hemisphere's specialization must be sent to the other hemisphere for processing. However, several studies suggest that both hemispheres can perceptually decode verbal information (Moscovitch, 1976; Day, 1977; Friedman et al., 1982) but the left hemisphere is more efficient for right handed individuals.

Friedman et al. (1982) had subjects combine a verbal memory load task with a same-different judgement task of nonsense syllables. For the verbal memory load task, subjects remembered several nonsense words which were presented to the center of the visual field. During the retention interval of the memory load task, two nonsense syllables were presented to the left or right visual field. Subjects indicated with fingers on both hands if the syllables were the same or different. The single to dual task performance decrements indicated that on right visual field trials both the memory task and the name match task use left hemisphere resources. However, on the left visual field trials the name match stimuli are received and processed (at least partially) by the right hemisphere. These results suggest that the right hemisphere can complete simple verbal processing associated with perceptual decoding such as physical identity and name identity of letters.

Therefore, it has been suggested that the description of the hemispheres as committed to either verbal or spatial processing, is inadequate and simplistic (Polson and Friedman, 1988). The relative efficiency of the two hemispheres in completing the same task may differ because each hemisphere may use a different composition of resources to complete the task (Polson and Friedman, 1988).

The third assumption of Friedman and Polsons' (1981) model is that the resources of each hemisphere can be allocated to any task. The implication is that interferences can occur between tasks that one would traditionally think of as requiring different resources. Kee, Bathurst, and Hellige (1983) found that right hand finger tapping was more disrupted by concurrent verbal tasks than left hand finger tapping. Friedman, Polson and Dafoe (1988) had right handed males concurrently perform a verbal memory task and finger tapping task. Performance on the motor task and the verbal task was poorer when the right hand completed the finger tapping task. These results support a model in which the hemispheres have contralateral control of motor responses and the left hemisphere is dedicated to verbal processing. Tasks which require seemingly different resources such as verbal and motor resources can interfere with one another if they require the resources of the same hemisphere.

Individual differences. The pattern and degree of cerebral laterality varies in individuals (Bryden, 1982; Hellige, Bloch and Taylor, 1988; Hellige and Wong, 1983). Studies using bilateral presentation of verbal information have found that right handers generally show a right visual field advantage while left handed subjects yield mixed results (Piazza, 1980; Schmuller and Goodman, 1979). Dichotic listening and visual laterality studies using right handed subjects suggest that there is a lesser degree of left hemisphere specialization for verbal processing in subjects with left-handed relatives (Mckeever, VanDeventer, and Suberi, 1973; Kee et al., 1983).

In addition, there appear to be gender differences in laterality (Bryden, 1979; McGlone, 1980; Harshman, Hampson and Berenbaum, 1983). Although the results are mixed, right handed males tend to show stronger lateralization patterns for verbal and spatial functions. In other words, verbal processing in males tends to be more exclusively controlled by the left hemisphere than for females. In an attempt to control for individual differences in cerebral organization, studies have used right handed individuals with no family history of left handedness. Many of the studies by the research groups of Wickens and Polson and Friedman have tested only male subjects or not reported gender differences.

Polson and Friedman (1988) preselected right handed individuals to be subjects by only choosing subjects that met a minimum criterion of right visual field dominance for verbal information. They assume that once these tasks are presented centrally, the hemisphere that is most efficient at verbal processing will complete the task. Therefore, the hemispheres as resources approach suggests that the left hemisphere of right handed subjects will assume most of the processing demands of a centrally presented verbal task even though the information is available to both hemispheres.

A Comparison of the Two Models

Friedman and Polson's (1981) model has implications for dual task performance which are different from the Task Hemispheric Integrity Principle. The Hemispheres as

Resources Model suggests that two tasks which require similar resources (ex. verbal resources) may be performed efficiently together if each hemisphere allocates resources to one task. Polson and Friedman (1988) believe the importance Wickens places on the processing code dimension (verbal/spatial) is an exaggeration since both the left and right hemisphere are capable of processing verbal and nonverbal information.

The hemispheres as resources approach also suggests that there may be performance differences between the hands during single task trials. For example, performance on single task trials should be maximized when one hemisphere allocates resources to control the central processing of a task and the other hemisphere controls the response processes (Polson and and Friedman, 1988). On the other hand, Wickens maintains that performance differences between the hands on single task trials cannot be accounted for by the task hemispheric integrity principle (Carswell and Wickens, 1985).

Auditory Techniques

Both of the above research programs have used mostly visual tasks in studying laterality issues. Wickens uses two concurrent visual tasks and Polson and Friedman use visual stimuli presented to the right and left hemisphere. Hemispheric differences have been investigated also by dichotic listening techniques which lateralizes the presentation of auditory information. In dichotic listening, a different auditory stimulus is presented to each ear at the same time and the subject is required to make an identifying response.

Each ear has a contralateral (to opposite hemisphere) and an ipsilateral (to the same hemisphere) pathway which transmits auditory information to the two hemispheres. Results of animal studies suggest that these pathways are not equal in strength and that the contralateral pathway is stronger (Kimura, 1961). According to Kimura's model, the technique of dichotic listening further suppresses the strength of the ipsilateral pathways so that the information is almost exclusively projected to the contralateral hemisphere. During dichotic trials, a verbal stimulus presented to the right ear has direct access to the left hemisphere while a left ear stimulus is first projected to the right hemisphere and then travels to the left hemisphere via the corpus callosum. Numerous studies have found a right ear performance advantage for verbal information presented dichotically (Kimura, 1967; Studdert-Kennedy and Shankweiler, 1970; Geffen & Quinn, 1984; Bryden & Murray, 1985). This right ear advantage is taken as evidence that the left hemisphere is superior at verbal processing since stimuli presented to the right ear are first available to the left hemisphere.

Other studies have found a left ear advantage for nonverbal stimuli such as tones, musical passages and vocal nonspeech sounds (Gordon, 1980; Mathieson, Sainsbury & Fitzgerald, 1990). The left ear inputs are projected to the right hemisphere and assumed to be processed there. Although the results are mixed, the left ear advantage for tones suggests the right hemisphere is involved in processing nonverbal stimuli.

Kinsbourne (1973, 1975) proposed that right ear advantages for verbal stimuli are attributed to attentional differences. During dichotic experiments, the verbal nature of the stimuli activates the left hemisphere. This priming of the left hemisphere makes the subjects more receptive to stimuli presented to the right ear. However, the results of other studies suggest that attentional differences are not the sole determinant of the right ear advantage found in dichotic studies (Goodglass & Calderon, 1977; Ley & Bryden, 1982; Bryden & Murray, 1985).

Lab Research

An intitial study at this lab tested the task hemispheric integrity principle using a dichotic listening task time shared with a flight simulator task which is spatial in nature. This study found effects which support the Task Hemispheric Integrity Principle. Subsequent research has attempted to identify the aspect of the spatial task which was responsible for the ear/hand effects without much success. Guerrete (1989) tested the predictions of the Task Hemispheric Integrity Principle and the Hemispheres as Resources Model using a series of spatial tasks. Subjects time-shared the dichotic listening task with spatial tasks that required distinct resources. She found mixed support for both of the models. The present study compares the predictions of these models during verbal information processing.

Friedman and Polson use a dual task paradigm in which one task is a memory load task and one task is identified as a target task. One specific memory load task was used repeatedly in the key studies which provide support for Friedman and Polson's model of hemispheric specialization (Friedman et al. 1982; Herdman and Friedman, 1985; Friedman et al., 1988). The stimuli for this task were nonsense words composed of three consonants separated by vowels (Consonant-Vowel-Consonant-Vowel-Consonant). When the task began, several nonsense words were presented to the center of the visual screen and the subjects were asked to read the words aloud. Then the words disappeared during the retention interval. After the retention interval the subjects began to recall the words. The second verbal task in each of these studies was completed during the retention interval of the first task.

Hellige and Wong (1983) used a similar memory load task as previous experiments, but the specific stimuli were low imagery nouns. This study paired the memory task with a dichotic listening task and found results which support Friedman and Polson's model of hemispheric processing. For listeners who showed a right ear advantage, the verbal memory task reduced the recognition of right ear stimuli (left hemisphere processing) but not the recognition of left ear stimuli (right hemisphere processing).

Studies which compared verbal and nonverbal load task suggest that the verbal nature of the load task is important in obtaining the pattern of results predicted by the Hemispheres as Resources Model. Hellige and Wong (1983) found that a nonverbal memory task (remembering complex shapes) did not reduce the recognition of either left or right ear dichotic stimuli. The importance of the verbal nature of the concurrent task has also been found in visual laterality studies (Hellige et al., 1979). Hellige et al. (1979) found that introducing a concurrent nonverbal memory task did not interfere with word recognition.

If the verbal nature of the load task is important, do these patterns of results also generalize to concurrent tasks which are not identical to the working memory load task used by previous studies? There are other tasks which are ostensibly verbal in nature which do not require a subject to maintain a list of words or nonsense words in working memory. One purpose of the present study is to determine if the predictions of the Hemisphere as Resources Model can be generalized to dual task combinations which use other types of verbal processing tasks.

Purpose

The purpose of the present study is to determine the hemispheric effects of verbal information processing on task performance. This study examined different levels of verbal processing using two visual (antonym match and continuous recall) and one auditory (dichotic listening) verbal task. The concurrent performance of two tasks was used to compare the importance of ear of attention, hemisphere of processing and response hand. This study tested the predictions of the Task-Hemispheric Integrity Principle and the Hemispheres as Resources Model.

Hypotheses

Single Task Hypotheses

The subjects performed single task trials of the dichotic listening task, the antonym task and the continuous recall task. Single task trials were used as a baseline for comparison to dual task trials. Although the subject's performance on these trials is not the main focus of the present study, the Hemispheres as Resources Model suggests there should be single task differences. Wickens' Resource Model and the Task Hemispheric Integrity Principle were developed to account for dual task performance and cannot account for single task differences (Carswell & Wickens, 1985). Therefore, the following sections present the single task hypotheses for each task based on previous literature and the Hemispheres as Resources Model of Friedman and Polson (1981).

Dichotic listening. The dichotic listening task presents a different stop consonant to the two ears at the same time. The subject is instructed to pay attention to only one ear and indicate the presence or absence of the target stimulus.

Many dichotic listening studies have found a right ear advantage for right handed individuals (Geffen & Quinn, 1984; Bryden & Murray, 1985). According to the Hemispheres as Resources Model, the left hemisphere may be more efficient at verbal processing. This model predicts an advantage for right ear attention to stimulus presentations (left hemisphere processing). Hypothesis 1: It was hypothesized that there will be a right ear advantage for the dichotic listening task.

The Hemispheres as Resources model does not suggest that there would be overall hand effects. However, the hand effect may be moderated by the ear of attention. This model predicts better performance when both hemispheres share the processing requirements of a task (White and Minor, 1990). Both hemispheres would share responsibilities if one

hemisphere processed the task and the other hemisphere controlled the responses. For the present study, sharing of processing responsibilities may occur during 1) right ear attention (left hemisphere processing) and left hand response control (right hemisphere processing) and 2) during left ear attention trials with right hand response control.
Hypothesis 2: It was hypothesized that there would be superior performance on the dichotic listening task when the hand of response is contralateral to the ear of attention.

Antonym match and continuous recall tasks. The antonym match task visually presents two English words and the subject must decide whether the words are opposite in meaning. The antonym task stimuli consists mostly of words which represented abstract concepts and verbs (for example, hunger, freedom, obstruct). The antonym match task is a standardized loading task that places demands upon mental resources associated with the manipulation and comparison of semantic information (Shingledecker, 1984). The antonym task requires the subject to retrieve word meanings from long term memory, retain those meanings in working memory and make a qualitative comparison of the words to decide if the words are opposite in meaning.

Research suggests that the right hemisphere can perceptually decode information when it relates to physical attributes (Friedman et al., 1982). The right hemisphere should not be able to process the antonym match task completely since the task requires more than just physical decoding of stimuli. Research with split brain patients suggests the right hemisphere can identify simple nouns (Springer and Deutsch, 1985) and words in the vocabulary of 10 year olds (Zaidel, 1978). It is not clear how split brain research should be interpreted and applied to normal individuals (Springer and Deutsch, 1985). However, the antonym match task in the present study uses words which represent abstract concepts. Also, the antonym task requires a comparison of word meanings whereas split brain research only required the subjects to identify the words. Therefore, it is assumed that the antonym match task requires verbal processing resources of the left hemisphere.

In the continuous recall task, subjects must remember serially presented digits and compare the current stimulus to a previously presented item. The continuous recall task is a standardized loading task designed to place demands upon processing resources associated with encoding and storage in working memory (Shingledecker, 1984). The task uses working memory functions by requiring subjects to accurately maintain, update, and access a store of information on a continuous basis. Both the continuous recall task and the nonsense memory load task used by previous research require verbal processing resources.

The continuous recall task differs in some ways from the memory load task of nonsense words used by previous research. The former task uses one digit numbers for stimuli while the latter task uses pronounceable nonsense words. The continuous recall task requires the simultaneous retention of a number and recall of a previously presented number with the retention and recall performed in an overlapping pattern. On the other hand, the memory load task of nonsense words, has a distinct retention phase and a distinct recall phase.

Studies have found that right handed individuals show a right visual field advantage for verbal tasks which indicates the left hemisphere is superior at verbal processing for these individuals (Hellige & Cox, 1976; Hellige, 1978; Hellige et al., 1979; Friedman et al., 1982). Polson and Friedman (1988) assume that the left hemisphere will continue to process a verbal task when it is presented to the center of the visual field. Therefore, the Hemispheres as Resources approach suggests that the left hemisphere of right handed subjects will complete most of the processing demands of the antonym match task and the continuous recall task.

Again, the Hemispheres as Resources Model suggests that superior performance will be achieved when the two hemispheres share the processing requirements of a task (Friedman & Polson, 1981). Both hemispheres would share responsibilities if one hemisphere processes the task and the other hemisphere controls the responses. If the antonym task and continuous recall task are processed by the left hemisphere, responding with the left hand (right hemisphere processing) would result in superior performance than right hand responding (left hemisphere processing). Hypothesis 3: It was hypothesized that there would be superior left hand performance on the single task trials of the antonym and continuous recall tasks.

The Hemispheres as Resources Model does not address gender differences. Previous research on gender differences of cognitive ability have been mixed. In general, previous research has found females to be superior at verbal tasks (Maccoby & Jacklin, 1974; Wittig & Peterson, 1979; Harshman, Hampson & Berenbaum, 1983). Hypothesis 4: It was hypothesized that the females would better performance on the antonym and continuous recall tasks.

Dual Task Hypotheses

The subjects performed the dichotic listening task concurrently with the antonym task and the dichotic listening task concurrently with the continuous recall task. The following sections discuss the rationale for the dual task hypotheses for Wickens' Resource Model (1980) and the Hemispheres as Resources Model of Friedman and Polson (1981).

Wickens: Dual Task Hypotheses. According to Wickens, all of the tasks used in the present study use the verbal processing code and will be processed by the left hemisphere. In addition, all the tasks fall into the early stage of processing on the stage of processing dimension (Early is perceptual encoding/ central processing; Late is response processing) of Wickens' (1980) Resource Model. Wickens' multiple resource model suggests that there would be decrements from single to dual task performance for the dichotic listening task, the antonym task and the continuous recall task since the three tasks use the same resources (early stage processing and verbal processing). There should be no performance differences on the dichotic task between the dichotic listening and antonym match dual task condition and the dichotic and continuous recall dual task condition since both of these combinations use the same resources according to the three dimensional model. Hypothesis 5: Based on Wickens' resource model, it was hypothesized that there would be decrements on the dichotic listening task from single to dual task trials but no differences between the dichotic and antonym dual task conditions and the dichotic and continuous recall dual task conditions. Hypothesis 6: Based on Wickens' resource model, it was hypothesized that there would be decrements on the antonym and continuous recall tasks from single to dual task performance.

Wickens' model might also suggest there should be a right hand advantage for responding to the verbal tasks during dual task conditions. Since the left hemisphere will process the tasks (according to Wickens), the shortest response path is from the left hemisphere to the right hand. Hypothesis 7: Based on the Task Hemispheric Integrity Principle, it was hypothesized that there would a right hand advantage for responding to the tasks during dual task conditions.

Moreover, the right ear stimuli for the dichotic listening task are processed by the left hemisphere and the left hemisphere directly controls the right hand. Wickens assumes that left ear stimuli are projected to the right hemisphere but must be sent to the left hemisphere for processing. Therefore, the shortest processing route is from right ear stimuli to right hand responding. Hypothesis 8: Based on the Task Hemispheric Integrity Principle, it was hypothesized that there would be better performance for the right ear attention - right hand combination during the dual task conditions of the dichotic listening task.

Friedman and Polson: Dual Task Hypotheses. Many of the dual task combinations used in the present study differ only in the degree to which left hemisphere resources are demanded. For example, the concurrent performance of the dichotic listening and the antonym match task represent one group of four dual task combinations. The four dual task conditions can be described by the ear of attention and hand of response for the dichotic listening task and are as follows: 1) left ear attention and left hand response, 2) left ear attention and right hand response, 3) right ear attention and left hand response, 4) right ear attention and right hand response. The advantage of these comparisons is that these four conditions do not differ in the difficulty or complexity of the tasks. Therefore, differences between these conditions can be more confidently attributed to resource allocation differences between the hemispheres than to task parameters such as difficulty or complexity differences between the dual task combinations.

As discussed previously, Polson and Friedman (1988) assume that verbal tasks will be processed and controlled by the left hemisphere though the task is presented to the center of the visual field and available to both hemispheres. The Hemispheres as Resources approach suggests that the left hemisphere of right handed subjects completes most of the processing demands of the antonym match task and the continuous recall task. Right ear dichotic stimuli will be processed by the left hemisphere if the ipsilateral pathways are suppressed in dichotic listening (Kimura, 1961). Therefore, a complete overlap of verbal resource requirements results when the subject attends to the auditory stimuli presented to the right ear (left hemisphere processing) and concurrently performs the antonym or continuous recall task (left hemisphere processing). Greater single to dual task performance decrements should be seen in this complete overlap condition as compared to left ear attention trials in which the dichotic stimuli are processed by the right hemisphere. Hypothesis 9: According to the Hemispheres as Resources Model, it was hypothesized that there would be greater dual task performance decrements during right ear attention trials than during left ear attention trials.

Summary of Hypotheses

Hypothesis 1: It was hypothesized that there would be a right ear advantage for the dichotic listening task.

Hypothesis 2: It was hypothesized that there would be superior performance on single task trials of the dichotic listening task when the hand of response is contralateral to the ear of attention.

Hypothesis 3: It was hypothesized that there would be superior left hand performance on the single task trials of the antonym and continuous recall tasks.

Hypothesis 4: It was hypothesized that the females would have better performance on the antonym and continuous recall tasks.

Hypothesis 5: Based on Wickens' resource model, it was hypothesized that there would be decrements on the dichotic listening task from single to dual task trials but no differences between the dichotic and antonym dual task and the dichotic and continuous recall dual task.

Hypothesis 6: Based on Wickens' resource model, it was hypothesized that there would be decrements on the antonym and continuous recall tasks from single to dual task performance.

Hypothesis 7: Based on the Task Hemispheric Integrity Principle, it was hypothesized that there would be a right hand advantage for responding to the tasks during dual task conditions.

Hypothesis 8: Based on the Task Hemispheric Integrity Principle, it was hypothesized that there would be better performance for the right ear - right hand combination during the dual task conditions of the dichotic listening task.

Hypothesis 9: According to the Hemispheres as Resources Model, it was hypothesized that there would be greater dual task performance decrements during right ear attention trials than during left ear attention trials.

METHOD

Subjects

Sixty-four subjects (32 male, 32 female) were recruited from undergraduate psychology classes at Old Dominion University. Subjects who volunteered to participate were given extra credit points applicable towards their course grade. All subjects had normal or corrected to normal vision (20/20) and normal conversational hearing. They ranged from 18 to 34 years of age. Subjects were right-handed with no family history of left-handedness as determined by the Annett Handedness Questionnaire. Subjects also had to pass minimum criteria on each of the tasks. The data from four subjects were replaced because they did not meet the minimum criteria on one of the tasks. The data from one subject was replaced due to experimenter error during data collection.

Design

The present study is a 2 (ear of attention) X 2 (hand of response) X 2 (gender) X 3 (level of verbal processing) X 16 (subjects) repeated measures design. The between subjects variables are hand of response and gender while the within subjects variables include ear of attention and the level of verbal processing. The dichotic listening task must be completed with attention to the left ear and also with attention to the right ear. If one considers the left and right ear attention trials for the dichotic listening task as separate tasks, there are four single tasks and four dual tasks. The order of these eight tasks was counterbalanced using a latin square design. Two male and two female subjects were randomly assigned to each of the eight task orders.

Independent Variables

There are four independent variables of interest in the present study. The first independent variable is hand of response; subjects were randomly assigned to one of the two conditions. One half of the male and one half of the female subjects performed the dichotic listening task with their right hand and the other tasks with their left hands. The remaining subjects responded to the dichotic listening tasks with their left hand.

The second independent variable is the ear of attention for the dichotic listening task. For each trial (including single and dual task trials) subjects were instructed to attend and respond only to the stimuli presented in the right or left ear. The order of ear attention was counterbalanced as described in the design section.

The third independent variable is the three task combinations of the dichotic listening task. The levels of this variable are 1) the dichotic task performed alone, 2) the concurrent performance of the dichotic task and the antonym match task, and 3) the concurrent performance of the dichotic task and the continuous recall task.

The forth independent variable is the gender of the subject.

Apparatus

The auditory stimuli for the dichotic listening task were recorded on audio tape, played on a JVC stereo and presented to the subjects through Koss SST/5 headphones. When the stimuli are played, it starts a timer by opening a voice actuated relay. A lever was used by the subjects to respond to the stimulus. As soon as the subject pushes the lever, the relay is closed, the clock is stopped and the reaction time for that stimulus trial is recorded. The dichotic listening task was run on an IBM compatible personal computer.

The antonym match task and the continuous recall task were both run on a Commodore 64 micro computer with a Commodore 1541 disk drive. The stimuli were presented to the subjects on a monochrome monitor. A box with a dual action return to center lever was used to make the responses. The software for the tasks was the Criterion Task Set (CTS) version 2.0.

The Annett Handedness questionnaire was used as a screening device to assess right hand dominance (Annett, 1985). The questionnaire asks subjects to identify which hand they use for everyday activities such as cutting with scissors, unscrewing the lid of a jar and writing a letter.

The vocabulary test of the Weschler Adult Intelligence Scale-Revised (WAIS-R) was used to assess the verbal ability of the subjects. The vocabulary test is one of five tests that make up the verbal score of the WAIS-R. The vocabulary test has a reliability of .96 and a correlation of .85 with the overall verbal score of the WAIS-R (Wechsler, 1981).

Experimental Tasks

Three tasks were used in the present study. A dichotic listening task was used to present stop consonants laterally. The two remaining tasks were presented visually and consisted of an antonym match task and a continuous recall tasks in which subjects had to recall a digit presented previously. The two latter tasks were incorporated in the Wright-Patterson Criterion Task Set. Pilot testing and validation studies were conducted at the U.S. Air force Aerospace Medical Research Laboratory to standardize training requirements and task parameters (Shingledecker, 1984).

Dichotic Listening Task

The dichotic listening task presented a series of stop consonant-vowel combinations (i.e. ba, ca, da, ga, pa, and ta) to the subject. The subject heard one sound presented to one ear and simultaneously heard another sound presented to the other ear. The subject was instructed to pay attention to only one ear for the presentation of a specific target (i.e. "ca"). In front of the subject was dichotic listening response box with a dual action return to center lever. The subject indicated if the target was present by pressing the lever to the "yes" position and pressing the lever to the "no" position if the target was not present in the attending ear. The subject was instructed to respond as quickly and accurately as possible after each stimulus presentation. Appendix A contains the instructions to the subjects for the dichotic listening task. Each task trial was three minutes and consisted of a series of ninety dichotic stimuli presented at the rate of one pair every 2.0 seconds. Every subject had to get at least one hit during each three minute trial in order to pass the minimum criterion for the dichotic listening task.

<u>Antonym Match Task</u>

The linguistic processing tasks were designed to place demands on the resources associated with the manipulation and comparison of linguistic information (Shingledecker, 1984). The CTS battery contains linguistic processing tasks of three demand or difficulty levels: low, moderate and high. The high demand condition or antonym match task was used for the present study. The high demand task required subjects to compare the meaning of two words and decide if the word are antonyms. The stimuli are pairs of words which are presented on a computer screen. The subject must decide if the words are opposite in meaning or not opposite in meaning. There was a linguistic response box with a dual action lever in front of the subject. The subject responded by pressing the lever to the yes position for antonyms or to the no position to indicate that the words were not antonyms. The stimuli were presented until the subject responds or until the deadline of 5.0 seconds had elapsed. After the subject entered a response, the next pair of words was presented. Each task trial was three minutes in length. Each subject had to meet a minimum criteria of correctly identifying 70 percent of the word pairs when performing this task alone.

Continuous Recall Task

The continuous recall task was designed to place demands on resources associated with encoding and storage in working memory (Shingledecker, 1984). The low demand level of this task presents a series of randomly generated single digit numbers on a computer screen. A probe number and a test number are presented simultaneously. The top number is the probe number which must be compared to the bottom digit that was presented on the previous screen. Therefore, the subject must recall the previous number and decide if it is the same or different from the probe number. In addition, the test number on the current screen must be encoded in working memory so that it can be recalled for the next comparison. The current screen is presented until the subject makes a response or 5.0 seconds have elapsed. The subject responds to the current probe digit by pushing the lever to the "same" position or to the "different" position. After the subject makes a response, the next pair of numbers consisting of a probe digit and a test number is presented and the subject must repeat the procedure. Each of the trials continued for three minutes. Every subject had to meet the minimum criteria of correctly identifying at least 70 percent of the items for a three minute single task trial.

Procedure

When the subject arrived for the experimental session, the experimenter explained the basic testing procedures. The subject read and signed an informed consent which fully described all aspects of the testing session. In addition, the subject completed the Annett Handedness questionnaire to confirm that they were right hand dominant. The was subject also given a vision screening to test for normal vision.

Next the subject received instructions and practice on the single and dual task combinations. The subject was seated in front of a table on which rested a monochrome monitor, a dichotic listening response box and a response box for the visual tasks. For each task, the experimenter read aloud the task instructions to the subject from a script (APPENDIX A,B,and C). The experimenter told the subject which hand to use for each task. The hand assignment remained the same for each subject during the practice and experimental trials. After the instructions for a task were read to the subject, the subject completed a three minute practice trial for that task. Any questions that the subject had were answered at this time.

The subject completed a total of six practice trials which each lasted three minutes. All subjects performed the following practice trials in the same order: 1)single task- dichotic listening with attention to the left ear, 2) single task- dichotic listening with attention to the right ear, 3) single task- antonym match, 4) dual task- antonym match and dichotic listening with attention to left ear, 5)single task-continuous recall 6) dual task- Continuous recall and dichotic listening with attention to right ear.

After the completion of the practice trials the subject was given the opportunity to rest for five minutes before beginning the experimental trials.

At the start of the experimental trials, the experimenter reviewed the instructions for each task with the subject. The subjects completed eight task trials (1. antonym, 2. recall, 3. left ear dichotic, 4. right ear dichotic, 5. left ear dichotic and antonym, 6. right ear dichotic and antonym, 7. left ear dichotic and recall and 8. right ear dichotic and recall). The subjects attended to only one ear during each dichotic trial. Every task trial lasted three minutes with two minute intervals between tasks. The order of the task trials was counterbalanced according to a latin square design.

After the subject completed the eight experimental trials, the experimenter administer to the subject, the vocabulary test of the WAIS-R. For this test the experimenter asks the subject for definitions of a list of 35 words. The subject defines each word verbally and the tester writes down the subjects complete response. The subjects definition to each word is later scored against a set of strict criteria. A subject can earn 2, 1, or no points for each definition depending on the level of understanding and the quality of response. Every subject had to pass a minimum criteria of scoring at least 20 points on the vocabulary test out of a possible 70 points.

At the completion of the experiment, the subject was debriefed and thanked for their participation. The experiment lasted one hour and forty minutes.

Dependent Measures

Dichotic Listening Task

Several performance measures were computed for each trial of the dichotic listening task: 1) median reaction time for hits, 2) proportion of hits 3) median reaction time for correct rejections, 4) proportion of correct rejections, 5) proportion of misses, 6) median false alarms, 7) proportion of false alarms, 8) proportion of false alarms to targets in the nonattending ear and 9) proportion of no responses.

A hit occurred when the target was present in the attending ear and the subject indicated that the target was present with a 'yes' response. The proportion of hits made by the subjects during each trial was computed by dividing the number of hits per trial by the total number of possible hits which was 15 for each 3 minute trial. A correct rejection occurred when the target was not present in the attending ear and the subject indicated that the target was not present with a 'no' response. The proportion of correct rejections was computed by dividing the number of correct rejections for each trial by 75 which is the total number of possible correct rejections.

A miss occurred when the target was present in the attending ear and the subject indicated that the target was not present with a 'no' response. Therefore, a miss represents an incorrect response by the subject. The proportion of misses was computed for each trial by dividing the number of misses by 15 which is the total number of possible misses. A false alarm occurred when the target was not present in the attending ear but the subject indicated, with a 'yes' response, that the target was present in the attending ear. The proportion of false alarms was computed by dividing the number of false alarms for a trial by the number of possible false alarms (75).

A subsample of the total number of false alarms was the false alarms that subjects made when the target was not present in the attending ear <u>but</u> it was present in the ear that they were trying to ignore. In other words, 'false alarms to targets in the nonattending ear' occurred when the subject responded that the target was present when in fact the target was not present in the attending ear but it was present in the nonattending ear. The proportion of 'false alarms to targets in the nonattending ear' was computed by dividing the number of false alarms to targets by 15 which is the number of targets that are present in the nonattending ear. This proportion is included to provide a measure of how well the subjects were able to attend to targets in just one ear.

A no response occurred when the subject did not respond within 1.5 seconds to the dichotic stimuli. The proportion of no responses was computed by dividing the number of no responses for a trial by the total number of stimulus presentations in one trial (90).

<u>Antonym and Continuous Recall Tasks</u>

The following dependent measures were calculated for both the antonym and continuous recall tasks: 1) median reaction time (for correct responses), 2) number of correct responses and 3) number of incorrect responses. Both the number of correct and incorrect responses are included in the analysis since the total number of stimuli presented during these task is a function of reaction time. For example, subjects with faster average reaction times were able to answer a larger number of stimulus presentations.

RESULTS

Dichotic Listening Task

Each of the dependent variables for the dichotic listening task were submitted to a 2 (hand) by 2 (gender) by 2 (ear of attention) by 3 (task level) analysis of variance. The levels of hand refer to the hand used by the subjects to respond to the dichotic listening task. The three task levels are the dichotic listening task performed alone, the dual task performance of the dichotic listening and antonym tasks and the dual task performance of the dichotic listening and the continuous recall task.

Hits: Reaction TIme

The median reaction time was computed for each subject for the hits during every repetition of the dichotic listening task. Table 1 shows the source of variation table for the median reaction times to hits. There was a significant main effect for task for the median reaction time to hits, $F(2,120)=115.01$, $p<.05$. A Student Newman Keuls post hoc test showed there were significant differences in the reaction time to hits during the single and dual task trials with faster reaction times in the single task trials (M=672) as compared to the dual task with the antonym task (M=856) and the dual task with the

Table 1

Sources of variation for the median reaction time to hits for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	22693.5000	0.41	
Sex	1	99266.3438	1.80	
Hand X Sex	1	12742.0417	0.23	
S(Hand Sex)	60	3315147.1041	----	
Task	2	2875019.1615	115.01*	.2715
Sex X Task	2	30985.6094	1.24	
Hand X Task	2	15191.7344	0.61	
Hand X Sex X Task	2	49188.4115	1.97	
Task X S(Hand Sex)	120	1499912.0833	----	
Ear	1	7866.2604	0.51	
Sex X Ear	1	1327.5938	0.09	
Hand X Ear	1	170.6667	0.01	
Hand X Sex X Ear	1	1305.3750	0.08	
Ear X S(Hand Sex)	60	934222.4375	----	
Task X Ear	2	40704.5990	1.51	
Sex X Task X Ear	2	41623.9219	1.55	
Hand X Task X Ear	2	17290.6927	0.64	
Hand X Task X Ear X Sex	2	7406.8281	0.28	
Task X Ear X S(Hand Sex)	120	1615179.6250	----	

* $p<.05$

continuous recall task (M=854). There were no other significant main effects or interactions for the median reaction time to hits.

Hits: Proportion

Table 2 shows the source of variation table for the proportion of hits. There were significant main effects for task ($F(2,120)=166.50$, $p<.05$) and ear of attention ($F(1,60)=30.33$, $p<.05$) for the proportion of hits. A Newman Keuls post hoc test showed there were significant differences in the proportion of hits for each task level with the largest proportion of hits when the dichotic task was performed alone (M=.9018), the next largest proportion when the dichotic task was performed with the antonym task (M=.6278) and the smallest proportion of hits occurred when the dichotic task was performed concurrently with the continuous recall task (M=.5531). There was a larger proportion of hits when the subjects were attending to their right ears (M=.7507) than when they were attending to their left ears (M=.6369). There were no other significant main effects or interactions for the proportion of hits.

Correct Rejections: Reaction Time

The median reaction time for correct rejections was computed for each subject across tasks. Table 3 shows the source of variation table for the median reaction times to correct rejections. There was a significant main effect for

Table 2

Sources of variation for proportion of hits for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	0.0007	0.01	
Sex	1	0.0002	0.00	
Hand X Sex	1	0.0634	0.74	
S(Hand Sex)	60	5.1590	----	
Task	2	8.6218	169.32*	.3821
Sex X Task	2	0.0072	0.14	
Hand X Task	2	0.1074	2.11	
Hand X Sex X Task	2	0.0084	0.16	
Task X S(Hand Sex)	120	3.0552	----	
Ear	1	1.2300	30.05*	.0545
Sex X Ear	1	0.0669	1.63	
Hand X Ear	1	0.0474	1.16	
Hand X Sex X Ear	1	0.0445	1.09	
Ear X S(Hand Sex)	60	2.4556	----	
Task X Ear	2	0.0128	0.48	
Sex X Task X Ear	2	0.0449	1.69	
Hand X Task X Ear	2	0.0245	0.92	
Hand X Task X Ear X Sex	2	0.0216	0.81	
Task X Ear X S(Hand Sex)	120	1.5896	----	

* $p<.05$

Table 3

Sources of variation for the median reaction time to correct rejections for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	15926.3776	0.40	
Sex	1	167793.5651	4.21*	.0169
Hand X Sex	1	35516.2734	0.89	
S(Hand Sex)	60	2391286.1979	----	
Task	2	4888788.2865	211.74*	.4934
Sex X Task	2	56562.8802	2.45	
Hand X Task	2	68221.1615	2.95	
Hand X Sex X Task	2	30181.9219	1.31	
Task X S(Hand Sex)	120	1385312.0833	----	
Ear	1	22955.6276	4.71*	.0023
Sex X Ear	1	24.5026	0.01	
Hand X Ear	1	14320.3776	2.94	
Hand X Sex X Ear	1	7499.5026	1.54	
Ear X S(Hand Sex)	60	292124.4896	----	
Task X Ear	2	2228.3490	0.28	
Sex X Task X Ear	2	9377.5052	1.19	
Hand X Task X Ear	2	43906.7240	5.59*	.0044
Hand X Task X Ear X Sex	2	6022.8802	0.77	
Task X Ear X S(Hand Sex)	120	470883.5417	----	

* $p<.05$

gender ($F(1,60)=4.21$, $p<.05$) with males (M=825) responding faster than females (M=866) for reaction times to correct rejections. There was a significant effect for ear of attention with faster correct rejection responses made during right ear attention trials (M=838) as compared to left ear attention trials (M=853). There was a significant task effect for median reaction time to correct rejections, $F(2,120)=211.74$, $p<.05$. A Newman Keuls post hoc test indicated that responses were significantly faster during the single task trials (M=686) as compared to the dual task conditions. However, there was no difference between the dual task condition with the antonym task (M=927) and the dual task condition with the continuous recall task (M=924) for median correct rejections.

There was a three way interaction of hand, task and ear of attention for the median reaction time of correct rejections, $F(2,120)=5.59$, $p<.05$. Figure 2 shows the reaction time to correct rejections as a function of hand of response, task and ear of attention. A simple effects test indicated that during left ear attention trials, the right hand group had significantly different reaction times across tasks with single task trials being the fastest, dual antonym task next fastest and the dual continuous recall task the slowest reaction time. The left hand group had significantly different reaction times during left ear attention trials where single task trials were the fastest,

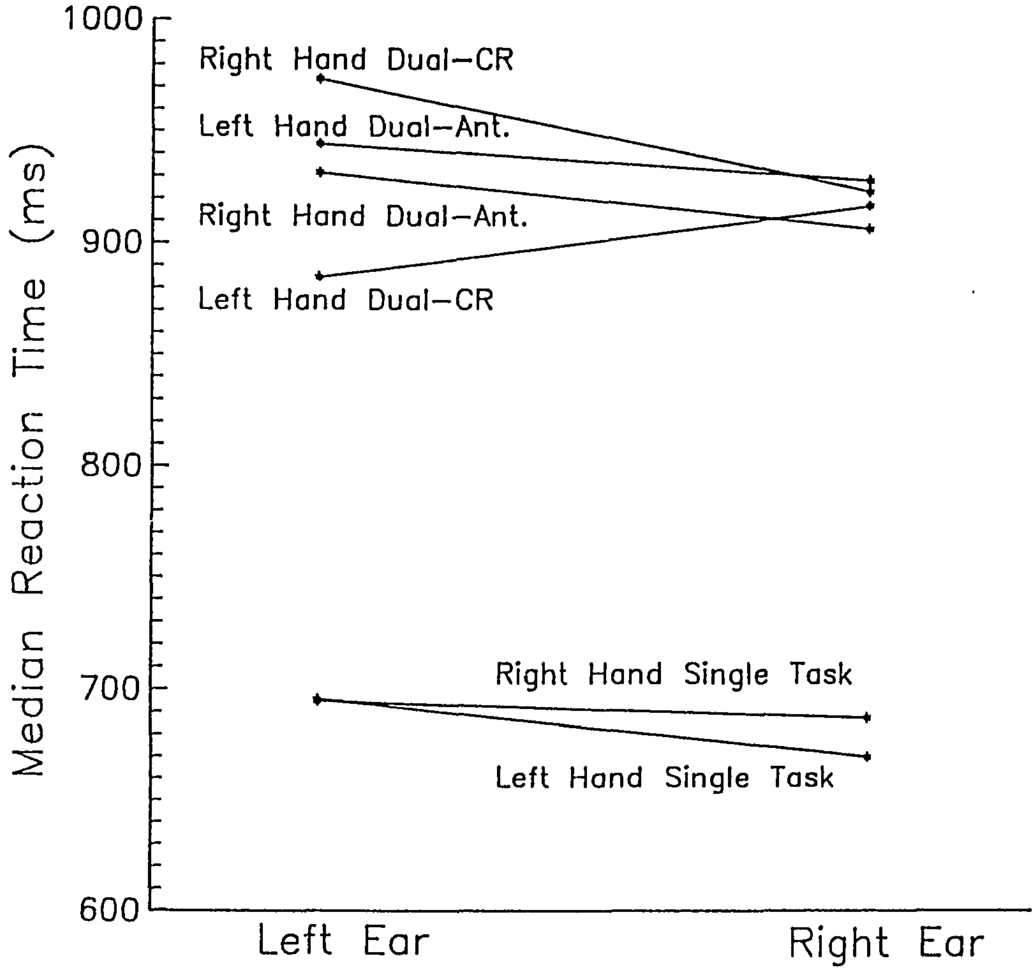


Figure 2. Reaction time to correct rejections on the dichotic listening task as a function of hand of response, task and ear of attention.

dual continuous recall task the next fastest and the dual antonym task had the slowest reaction times. During right ear attention trials both the left and right hand groups had significantly faster reaction times during single task trials as compared to the dual task trials. However, there was no significant difference between the reaction times of the dual antonym and dual continuous recall tasks.

During the dual continuous recall trials, the right hand group had faster reaction times to correct rejections with right ear attention (M=992) than with left ear attention (M=973). In contrast, the left hand group had significantly faster reaction times during the dual continuous recall task with left ear attention (M=884) than with right ear attention (M=916). There were no other significant differences in the interaction of hand, task and ear for reaction time to correct rejections on the dichotic listening task.

Correct Rejections: Proportion

The proportion of correct rejections was computed for each trial. Table 4 shows the source of variations for the proportion of correct rejections. There was a significant task effect for the proportion of correct rejections, $F(2,120)=5.49, p<.05$. A Student Newman Keuls post hoc test was performed on the means of the groups which indicated there were significant differences between the three task levels. The single task (M=0.77) of dichotic listening had

Table 4

Sources of variation for proportion of correct rejections for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	0.0083	0.01	
Sex	1	0.0560	0.70	
Hand X Sex	1	0.0033	0.04	
S(Hand Sex)	60	4.7970	----	
Task	2	5.4990	226.34*	.4275
Sex X Task	2	0.0457	1.88	
Hand X Task	2	0.0588	2.42	
Hand X Sex X Task	2	0.0067	0.28	
Task X S(Hand Sex)	120	1.4577	----	
Ear	1	0.0041	0.70	
Sex X Ear	1	0.0000	0.02	
Hand X Ear	1	0.0046	0.79	
Hand X Sex X Ear	1	0.0054	0.92	
Ear X S(Hand Sex)	60	0.3511	----	
Task X Ear	2	0.0164	1.90	
Sex X Task X Ear	2	0.0089	1.03	
Hand X Task X Ear	2	0.0113	1.34	
Hand X Task X Ear X Sex	2	0.0111	1.28	
Task X Ear X S(Hand Sex)	120	0.5192	----	

* $p<.05$

the highest proportion of correct rejections, the antonym task (M=0.57) the next highest proportion and the continuous recall task (M=0.49) had the smallest proportion of correct rejections. There were no other significant effects for the proportion of correct rejections.

Misses: Proportion

The proportion of misses was computed for each trial. Table 5 shows the source of variation table for the proportion of misses. There was a significant main effect for task, $F(2,120)=24.74, p<.05$. A Newman Keuls post hoc task indicated that there was a significantly larger number of misses during the dual task conditions (M=.1708, M=.1693) as compared to the single task periods (M=0.0833). There was no significant difference in the proportion of misses made during the dual task condition with the antonym task (M=0.1708) and the dual task condition with the continuous recall task (M=0.1693). There was a significant main effect for the ear of attention during the dichotic listening task, $F(1,60)=35.24, p<.05$. A larger proportion of misses was made when the subjects paid attention to their left ear (M=0.1930) than their right ear (M=0.0892). There were no other significant effects for the proportion of misses.

Total False Alarms: Reaction Time

The median reaction time to false alarms was computed for each trial. Table 6 shows the sources of variation for

Table 5

Sources of variation for proportion of misses for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	0.0278	0.52	
Sex	1	0.0097	0.18	
Hand X Sex	1	0.0097	0.18	
S(Hand Sex)	60	3.1834	----	
Task	2	0.6419	24.74*	.0676
Sex X Task	2	0.0343	1.32	
Hand X Task	2	0.0497	1.92	
Hand X Sex X Task	2	0.0077	0.30	
Task X S(Hand Sex)	120	1.5568	----	
Ear	1	1.0347	35.24*	.1089
Sex X Ear	1	0.0489	1.67	
Hand X Ear	1	0.0176	0.60	
Hand X Sex X Ear	1	0.0000	0.00	
Ear X S(Hand Sex)	60	1.7617	----	
Task X Ear	2	0.0310	1.79	
Sex X Task X Ear	2	0.0039	0.23	
Hand X Task X Ear	2	0.0306	1.77	
Hand X Task X Ear X Sex	2	0.0109	0.63	
Task X Ear X S(Hand Sex)	120	1.0406	----	

* $p<.05$

Table 6

Sources of variation for the median reaction time to false alarms for the dichotic listening task

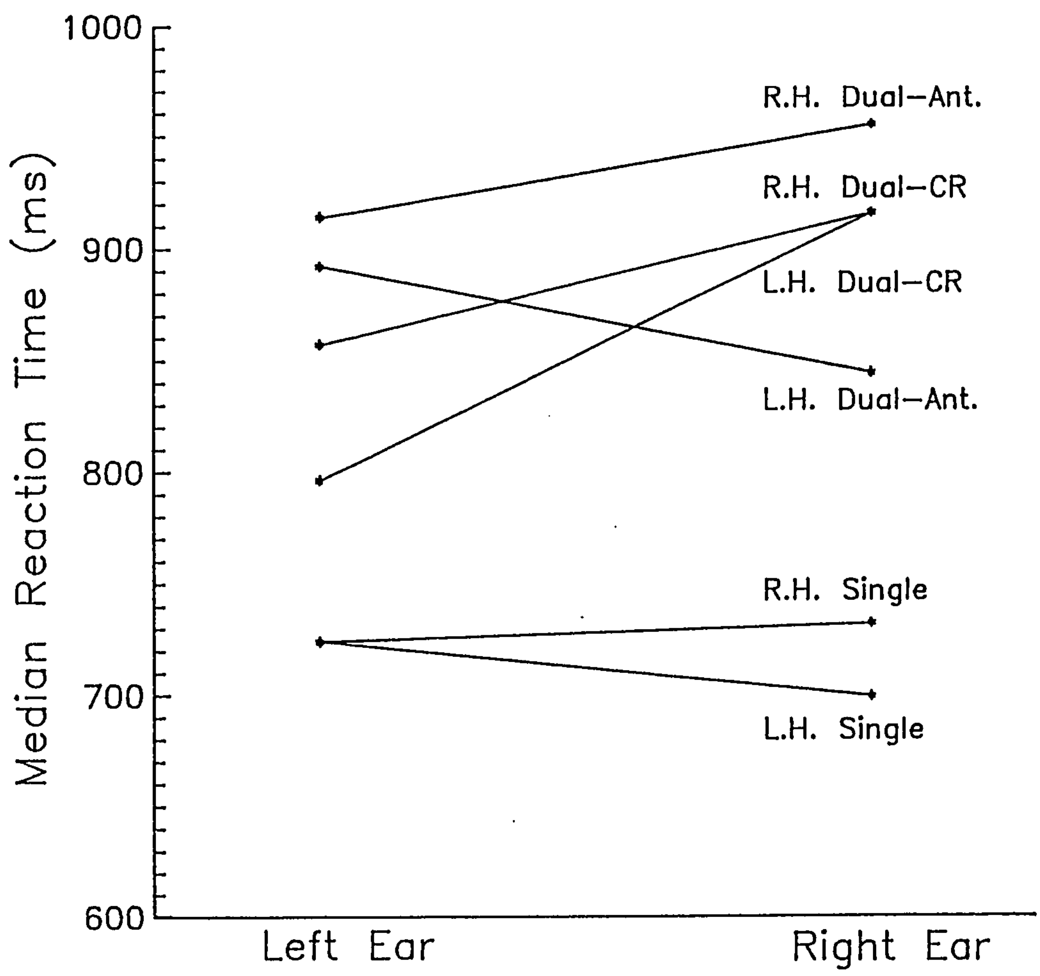
Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	11353.5000	0.16	
Sex	1	48600.0000	0.70	
Hand X Sex	1	70850.6667	1.02	
S(Hand Sex)	60	4166727.1250	----	
Task	2	2203142.4531	40.89*	.1476
Sex X Task	2	7056.2031	0.13	
Hand X Task	2	23710.6406	0.44	
Hand X Sex X Task	2	9868.5365	0.18	
Task X S(Hand Sex)	120	3232520.5000	----	
Ear	1	228.1667	0.01	
Sex X Ear	1	71613.3750	3.52	
Hand X Ear	1	360.3750	0.02	
Hand X Sex X Ear	1	6112.0417	0.30	
Ear X S(Hand Sex)	60	1219502.3750	----	
Task X Ear	2	75985.2552	1.33	
Sex X Task X Ear	2	34697.3594	0.61	
Hand X Task X Ear	2	45935.7344	0.80	
Hand X Task X Ear X Sex	2	262440.3177	4.58*	.0176
Task X Ear X S(Hand Sex)	120	3438639.0000	----	

* p<.05

the reaction time to total false alarms. There was a significant main effect of task for median reaction time to false alarms, $F(2,120)=40.89$, $p<.05$. A Newman Keuls post hoc indicated that the reaction time for false alarms were significantly faster in the single task condition (M=736 msec) as compared to either of the dual task conditions. There was no difference in the reaction time for false alarms between the concurrent performance of the dichotic task and antonym task (M=911 msec) and the concurrent performance of the dichotic task and the continuous recall task (M=877 msec).

There was also a significant four way interaction of the independent variables hand, gender, ear and task for the median reaction time of false alarms, $F(2,120)=4.58$, $p<.05$. Figure 3 shows the reaction time to false alarms for the males as a function of hand of response, task and ear of attention. A test of simple effects indicated that during the dual continuous recall task, the LEFT HAND MALE group had faster reaction times during left ear (M=795 ms) than right ear (M=916) attention trials.

Figure 4 shows the reaction time to false alarms of the females as a function of hand of response, task and ear of attention. During the dual continuous recall task, the LEFT HAND FEMALE group had faster reaction times during right ear (M=854) than left ear (M=951) attention trials. The RIGHT HAND FEMALE group had faster reaction times to left ear



<u>Figure 3.</u> Reaction time to false alarms for the males on the dichotic listening task as a function of hand of response, task and ear of attention.

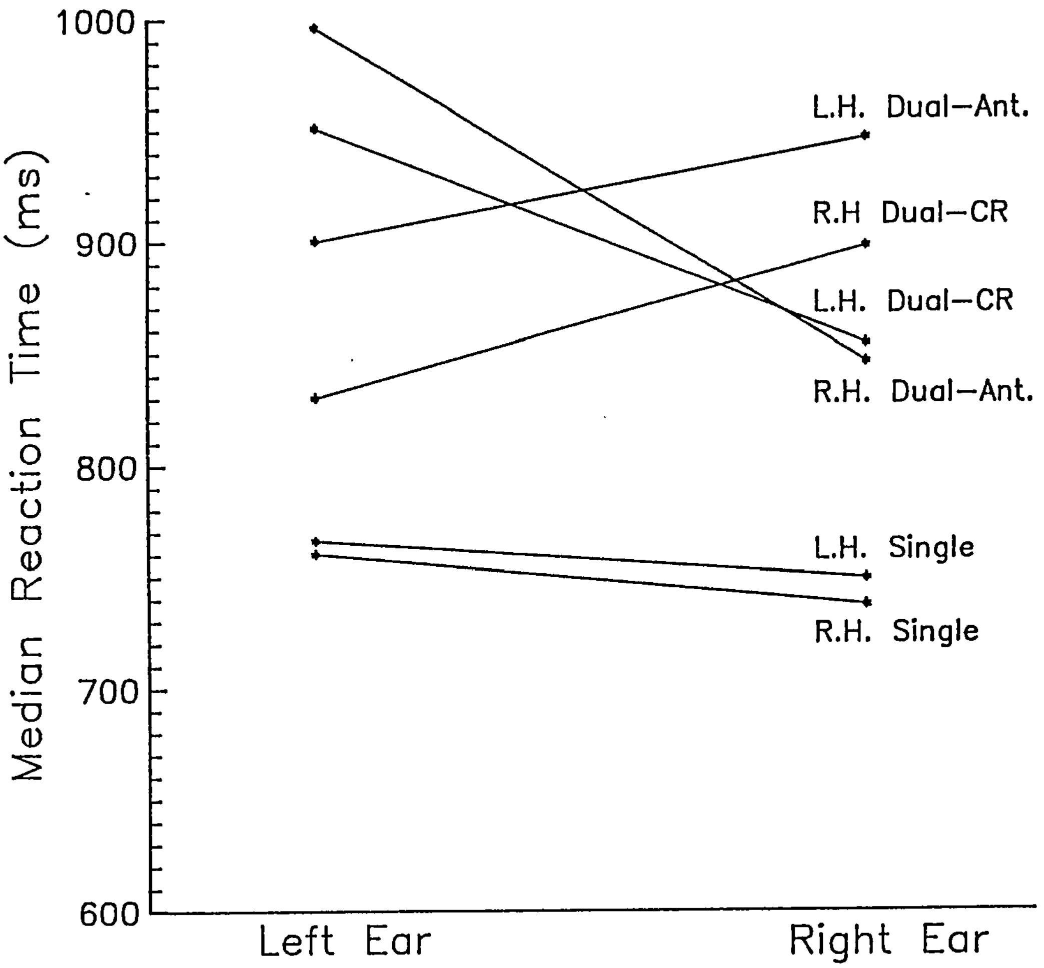


Figure 4. Reaction time to false alarms for the females on the dichotic listening task as a function of hand of response, task and ear of attention.

(M=830) then right ear (M=898) attention trials during dual continuous recall task trials. During dual antonym trials, the RIGHT HAND FEMALE group had faster reaction times to right ear (M=846) than left ear (M=996) attention trials. There were no other significant effects for the reaction time to false alarms.

Total False Alarms: Proportion

The proportion of false alarms was computed for each trial. Table 7 shows the sources of variation for the proportion of total false alarms. There was a significant main effect of task for the proportion of false alarms, $F(2,120)=9.31$, $p<.05$. A Newman Keuls post hoc test showed that there were significantly more false alarms for the single task trials (M=0.2070) as compared to both of the dual task conditions. There were no significant differences between dual antonym and dichotic condition (M=0.1832) and the dual continuous recall and dichotic condition (M=0.1722). There was a significant effect of the ear of attention for the proportion of false alarms, $F(1,60)=7.53$, $p<.05$. There were a larger proportion of false alarms when the subject was attending to their left ear (M=0.1958) as compared to when the subject was attending to their right ear (M=0.1791). There were no other significant effects for the proportion of false alarms.

False Alarms to Targets in the Nonattending Ear: Proportion

The proportion of false alarms to targets in the

Table 7

Sources of variation for proportion of false alarms for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	0.0084	0.12	
Sex	1	0.0114	0.16	
Hand X Sex	1	0.0008	0.01	
S(Hand Sex)	60	4.1699	----	
Task	2	0.0745	8.45*	.0139
Sex X Task	2	0.0112	1.27	
Hand X Task	2	0.0065	0.73	
Hand X Sex X Task	2	0.0005	0.06	
Task X S(Hand Sex)	120	0.5293	----	
Ear	1	0.0264	7.48*	.0049
Sex X Ear	1	0.0002	0.06	
Hand X Ear	1	0.0001	0.04	
Hand X Sex X Ear	1	0.0021	0.59	
Ear X S(Hand Sex)	60	0.2120	----	
Task X Ear	2	0.0044	0.89	
Sex X Task X Ear	2	0.0073	1.48	
Hand X Task X Ear	2	0.0037	0.75	
Hand X Task X Ear X Sex	2	0.0089	1.81	
Task X Ear X S(Hand Sex)	120	0.2940	----	

* $p<.05$

nonattending ear was computed for each trial. Over all tasks combinations the subjects committed an average proportion of 0.5014 false alarms to targets in the nonattending ear. Table 8 shows the sources of variance for the proportion of false alarms to targets in the nonattending ear.

There was a significant main effect of task for the proportion of false alarms to targets in the nonattending ear, $\underline{F}(2,120)=38.15$, $\underline{p}<.05$. A Newman Keuls post hoc test indicated there were significant differences in the proportion of false alarms to targets for each task level with the smallest proportion during the continuous recall dual task (M=0.4115), the next largest during the antonym dual task (M=0.4843) and the largest proportion during the single task trials (M=0.6083). There was a significant main effect of ear of attention, $\underline{F}(1,60)=30.58$, $\underline{p}<.05$. There was larger proportion of false alarms to targets in the nonattending ear when the subject was paying attention to their left ear (M=0.5602) than their right ear (M=0.4478). There were no other significant effects for the proportion of false alarms in the nonattending ear.

<u>No Responses: Proportion</u>

The proportion of no responses was computed for each trial. Table 9 shows the sources of variation for the proportion of no responses to the dichotic listening task. There was a significant task main effect for the proportion

Table 8

Sources of variation for proportion of false alarms to targets in nonattending ear for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	0.0741	0.65	
Sex	1	0.1400	0.34	
Hand X Sex	1	0.0245	0.11	
S(Hand Sex)	60	12.9236	----	
Task	2	2.5362	35.67*	.0956
Sex X Task	2	0.1690	2.38	
Hand X Task	2	0.0095	0.13	
Hand X Sex X Task	2	0.0256	0.36	
Task X S(Hand Sex)	120	4.2656	----	
Ear	1	1.2000	30.35*	.0452
Sex X Ear	1	0.0150	0.38	
Hand X Ear	1	0.0004	0.01	
Hand X Sex X Ear	1	0.0017	0.04	
Ear X S(Hand Sex)	60	2.3725	----	
Task X Ear	2	0.0070	0.16	
Sex X Task X Ear	2	0.0108	0.24	
Hand X Task X Ear	2	0.0408	0.91	
Hand X Task X Ear X Sex	2	0.0344	0.77	
Task X Ear X S(Hand Sex)	120	2.6906	----	

* $p<.05$

Table 9

Sources of variation for proportion of no responses for the dichotic listening task

Source of Variance	df	Sum of Squares	F	Eta Square
Hand	1	0.0958	1.98	
Sex	1	0.0412	0.85	
Hand X Sex	1	0.0039	0.08	
S(Hand Sex)	60	2.8999	----	
Task	2	6.4765	193.42*	.3286
Sex X Task	2	0.0550	1.64	
Hand X Task	2	0.0318	0.95	
Hand X Sex X Task	2	0.0055	0.17	
Task X S(Hand Sex)	120	2.0090	----	
Ear	1	0.0039	1.13	
Sex X Ear	1	0.0007	0.20	
Hand X Ear	1	0.0097	2.83	
Hand X Sex X Ear	1	0.0007	0.20	
Ear X S(Hand Sex)	60	0.2065	----	
Task X Ear	2	0.0046	0.72	
Sex X Task X Ear	2	0.0017	0.26	
Hand X Task X Ear	2	0.0206	3.21*	.0017
Hand X Task X Ear X Sex	2	0.0004	0.06	
Task X Ear X S(Hand Sex)	120	0.3847	----	

* $p<.05$

of no responses, $F(2,120)=193.42, p<.05$. A Newman Keuls post hoc test showed there were significant differences between each of the task levels. The smallest proportion of no responses occurred when the dichotic task was performed alone (M=0.0165), the next largest proportion occurred when the dichotic task was performed concurrently with the antonym task (M=0.2364) and the largest proportion occurred when the dichotic task and the continuous recall task were performed together (M=0.3256).

There was a significant three way interaction of task, hand of response and ear of attention for the proportion of no responses, $F(2,120)=3.21$, $p<.05$. Figure 5 shows the proportion of no responses for hand of response, task and ear of attention. A test of simple effects indicated this interaction is due to the left hand group which had fewer no responses during dual continuous recall with left ear attention than right ear attention. There were no other significant effects for the proportion of no responses.

Correlations for Measures of Task Performance

The intercorrelations of the dependent measures on the single task trials of the dichotic listening task are shown in Table 10. Reaction time to hits had significant positive correlations with reaction time to correct rejections (M=0.617) and reaction time to false alarms (M=0.620).

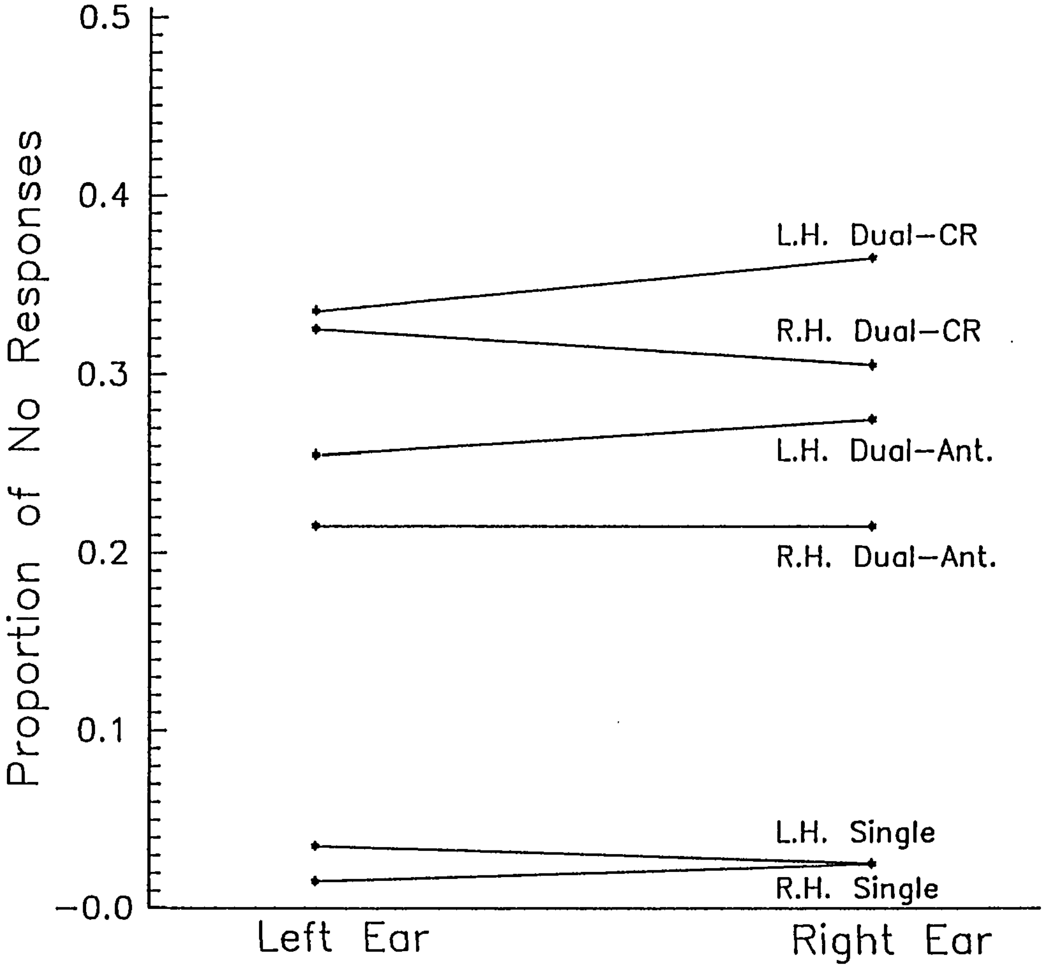


Figure 5. Proportion of no responses on the dichotic listening task as a function of ear of attention, hand of response and task.

Table 10

Correlations between the task performance measures of the dichotic listening task

Dichotic Performance Measures	Dichotic Performance Measures				
	RT Hits	P(Hits)	RT C.R.	P(C.R.)	P(Miss)
RT Hits	1.000				
P(Hits)	-0.255*	1.000			
RT C.R.	0.617*	0.034	1.000		
P(C.R.)	-0.113	0.028	-0.402*	1.000	
P(Miss)	0.262*	-0.951*	-0.080	0.035	1.000
RT F.A.	0.620*	-0.076	0.485*	0.130	0.062
P(F.A.)	0.055	-0.008	0.303*	-0.970*	-0.027
P(No resp)	0.243*	-0.147	0.432*	-0.250*	-0.003

* p<.05
note: correlations based on an N of 128

Table 10 (continued)

Correlations between the task performance measures of the dichotic listening task

Dichotic Performance Measures	Dichotic Performance Measures: RT F.A.	P(F.A.)	P(no resp)
RT Hits			
P(Hits)			
RT C.R.			
P(C.R.)			
P(Miss)			
RT F.A.	1.000		
P(F.A.)	-0.192	1.000	
P(No resp)	0.242*	0.015	1.000

* $p<.05$
note: correlations based on an N of 128

Antonym Task

Each dependent variable of the antonym task was submitted to a 2(hand) X 2(gender) X 3(task condition) analysis of variance. The independent variable hand refers to the hand which responded to the antonym task. The 3 levels of task condition were: 1) single task performance of the antonym task, 2) dual task performance of antonym task and right ear attention to dichotic listening and 3) dual task performance of antonym task and left ear attention to dichotic listening task.

The vocabulary scores on the WAIS vocabulary subtest were collected as a possible covariate for the performance scores on the antonym task. Table 11 shows the proportion of variance in each of the performance measures that is accounted for by the vocabulary score. The vocabulary scores do not account for a large proportion of the variation in performance scores. Therefore, the vocabulary scores were not used as a covariate in the analysis of variance of the antonym task performance measures.

Correct Responses: Reaction Time

The median reaction time to correct responses was computed for each trial of the antonym task. Table 12 shows the sources of variation table for median reaction time of correct responses. There was a significant main effect of gender ($F(1,60)=4.26$, $p<.05$) for the median reaction time of correct responses. Females (M=1681.16) had faster reaction

Table 11

Proportion of variance in antonym performance measures accounted for by vocabulary scores

	Antonym Performance Measures		
	Reaction Time	Number Correct	Number Incorrect
Vocabulary Score	0.0384	0.0977	0.1210

Table 12

Sources of variation for reaction time, number of correct and incorrect responses on the antonym task

Source of Variance	df	Sum of Squares	F	Eta Square
a. Reaction time				
Hand	1	205670.0333	0.20	
Sex	1	4478630.8333	4.26*	.0510
Hand X Sex	1	141267.0000	0.13	
S(Hand Sex)	60	63090223.4167	----	
Task	2	4687257.1667	18.68*	.0533
Sex X Task	2	155592.6667	0.62	
Hand X Task	2	61207.2917	0.24	
Hand X Sex X Task	2	4300.8750	0.02	
Task X S(Hand Sex)	120	15058959.3333	----	
b. Number of correct responses				
Hand	1	32.5052	0.13	
Sex	1	954.6302	4.02*	.0429
Hand X Sex	1	53.1302	0.21	
S(Hand Sex)	60	14842.1042	----	
Task	2	2625.5417	42.61*	.1180
Sex X Task	2	29.1667	0.47	
Hand X Task	2	21.2917	0.35	
Hand X Sex X Task	2	3.0417	0.05	
Task X S(Hand Sex)	120	3696.9583	----	
c. Number of incorrect responses				
Hand	1	18.1302	0.28	
Sex	1	66.5052	1.01	
Hand X Sex	1	2.7552	0.04	
S(Hand Sex)	60	3952.6458	----	
Task	2	474.8854	19.50*	.0783
Sex X Task	2	79.7604	3.28*	.0132
Hand X Task	2	4.1979	0.17	
Hand X Sex X Task	2	3.5729	0.15	
Task X S(Hand Sex)	120	1460.9167	----	

* $p<.05$

times than the males (M=1986.62) for the antonym task. There was a significant main effect for task condition, $F(2,120)=18.68$, $p<.05$. A Newman Keuls post hoc test indicates that the reaction times were significantly faster when the antonym task was performed alone (M=1614.38) as compared to the two conditions when the antonym task was performed concurrently with the dichotic listening task. However, there was no significant difference in reaction time between the antonym task performed concurrently with right ear attention (M=1965.50) and the antonym task performed concurrently with left ear attention (M=1921.81) to the dichotic task.

Correct Responses: Number

Table 12 shows the sources of variation for the number of correct responses for the antonym task. There was a significant main effect for gender ($F(1,60)=4.02$, $p<.05$) for the number of correct responses. The female subjects (M=51.00) correctly identified more word pairs per trial than the male subjects (M=46.44). In addition, there was a significant main effect of task condition for the number of correct responses, $F(2,120)=42.61$, $p<.05$. A Newman Keuls post hoc test revealed that there were significantly more correct responses in the single task condition (M=53.95) than in either the antonym and right ear attention trials (M=46.04) or the antonym and left ear attention trials (M=46.17). However, there was no significant difference in the number of correct responses for the two dual task conditions.

Incorrect Responses: Number

Table 12 shows the sources of variation for the number of incorrect responses for the antonym task. There was a significant task main effect for the number of incorrect responses to the antonym task, $F(2,120)=19.50$, $p<.05$. A Newman Keuls post hoc test indicated there were more incorrect responses during the dual task conditions as compared to the single task conditions (M=7.21). However, there was no significant difference between the antonym dual task with right ear attention (M=10.53) and the antonym dual task with left ear attention (M=10.57) for the number of incorrect responses on the antonym task.

There was a significant interaction between gender and task level ($F(2,120)=3.28$, $p<.05$) for the number of incorrect responses. Figure 6 shows the interaction of gender and task level for the number of incorrect responses. A test of simple effects indicated males made significantly more incorrect responses than females on the antonym task during dual task performance of the dichotic listening task with right ear attention. Both the males and females performance across task levels indicated that fewer incorrect responses were made during single task conditions as compared to both the dual task conditions. There were no

Figure 6. Number of incorrect responses on the antonym match task as a function of gender and task level.

other significant effects for the gender by task interaction for the number of incorrect responses.

Correlations with Dichotic Listening

The correlations between the dual task performance measures of the dichotic listening and the antonym task are shown in Table 13. Reaction time on the antonym task is not significantly correlated with any of the reaction time measures of the dichotic listening task (hits, correct rejections and false alarms). The number of correct responses on the antonym task had significant positive relationships with the proportion of hits and proportion of correct rejections on the dichotic listening task. Therefore, as the subject's performance on the antonym task improved so did performance on the dichotic listening task. In addition, the number of incorrect responses on the antonym task had significant positive relationships with the proportion of misses and proportion of false alarms on the dichotic listening task.

Continuous Recall

Each of the dependent measures for the continuous recall task was submitted to a 2(hand) X 2(gender) X 3(task condition) analysis of variance. The independent variable "hand" refers to the hand which responded to the continuous recall task. The three levels of the task condition were 1) single task performance of the continuous recall task, 2)

Table 13

Correlations between the dual task performance measures of the dichotic listening and antonym tasks

Dichotic Performance Measures	Antonym Performance Measures Reaction Time	Number Correct	Number Incorrect
RT Hits	0.08575	-0.13993	0.05952
Prop. Hits	-0.15921	0.28547*	-0.08549
RT Correct Rej.	0.14972	-0.03947	-0.10638
Prop. Correct Rej.	-0.21271*	0.25120*	-0.06525
Prop. Misses	-0.02028	-0.08829	0.21429*
RT False alarms	0.06468	-0.06784	0.01393
Prop. False alarms	-0.20497*	0.16682	0.30160*
Prop. No responses	0.36703*	-0.38932*	-0.15500

* p<.05
note: correlations based on an N of 128.

dual task performance of the continuous recall task and <u>right</u> ear attention to the dichotic listening task, and 3) dual task performance of the continuous recall task and <u>left</u> ear attention to the dichotic listening task.

<u>Correct Responses: Reaction Time</u>

The median reaction time of correct responses was computed for each trial. Table 14 shows the sources of variation for the median reaction time of correct responses for the continuous recall task. There was a significant task main effect for the median reaction time for the continuous recall task, $F(2,120)=42.22$, $p<.05$. A Newman Keuls post hoc test indicated there were significantly faster reaction times for the single task trials (M=877) as compared to the dual task trials. There was no significant difference in reaction time between the continuous recall-right ear dual task (M=1158) and the continuous recall-left ear dual task (M=1115).

<u>Correct Responses: Number</u>

The number of correct responses for each trial of the continuous recall task was computed. Table 14 shows the sources of variation for the number of correct responses of the continuous recall task. There was a significant task main effect for the number of correct responses to the continuous recall task, $F(2,120)=395.64$, $p<.05$. A Newman Keuls post hoc test indicated that subjects correctly answered significantly more items during the single task

Table 14

Sources of variation for the reaction time, number of correct and incorrect responses on the continuous recall task

Source of Variance	df	Sum of Squares	F	Eta Square
a. Reaction time				
Hand	1	13316.6719	0.07	
Sex	1	8125.0052	0.04	
Hand X Sex	1	42275.0052	0.21	
S(Hand Sex)	60	12037504.9375	----	
Task	2	2942176.2604	42.22*	.1512
Sex X Task	2	155578.1354	2.23	
Hand X Task	2	71394.9688	1.02	
Hand X Sex X Task	2	4814.7604	0.07	
Task X S(Hand Sex)	120	4181037.8750	----	
b. Number of Correct Responses				
Hand	1	450.1875	0.65	
Sex	1	212.5208	0.30	
Hand X Sex	1	1474.0833	2.12	
S(Hand Sex)	60	41815.8750	----	
Task	2	71066.2604	395.64*	.5640
Sex X Task	2	0.6979	0.00	
Hand X Task	2	17.1563	0.10	
Hand X Sex X Task	2	182.3854	1.02	
Task X S(Hand Sex)	120	10777.5000	----	
c. Number of Incorrect Responses				
Hand	1	0.7500	0.01	
Sex	1	114.0833	1.73	
Hand X Sex	1	357.5208	5.42*	.0211
S(Hand Sex)	60	3955.4583	----	
Task	2	9765.9479	226.73*	.5774
Sex X Task	2	88.3229	2.05	
Hand X Task	2	22.5313	0.52	
Hand X Sex X Task	2	25.4479	0.59	
Task X S(Hand Sex)	120	2584.4167	----	

* p<.05

trials (M=102) as compared to the dual task trials. There was no difference between left ear (M=62.26) dual task trials and right ear (M=60.21) dual task trials for the number of correct responses to the continuous recall task.

Incorrect Responses: Number

The number of incorrect responses of the continuous recall task was computed for each trial. Table 14 shows the sources of variation of the number of incorrect responses for the continuous recall task. There was a significant task main effect for the number of incorrect responses to the continuous recall task, $F(92,120)=226.73$, $p<.05$. A Newman Keuls post hoc test indicated there were significantly more incorrect responses during both of the dual task trials as compared to the single task trials (M=3.71). There were no significant differences between left ear dual task trials (M=18.64) and right ear dual task trials (M=19.04) for the number of incorrect responses to the continuous recall task.

There was a significant interaction between gender and hand of response on the continuous recall task for the number of incorrect responses, $F(2,60)=5.42$, $p<.05$. Figure 7 shows the number of incorrect responses for hand of response and gender. A simple effects test indicated that when using the left hand to respond, females (M=11.73) made fewer incorrect responses than males (M=16.00). There were no other significant differences for the interaction of

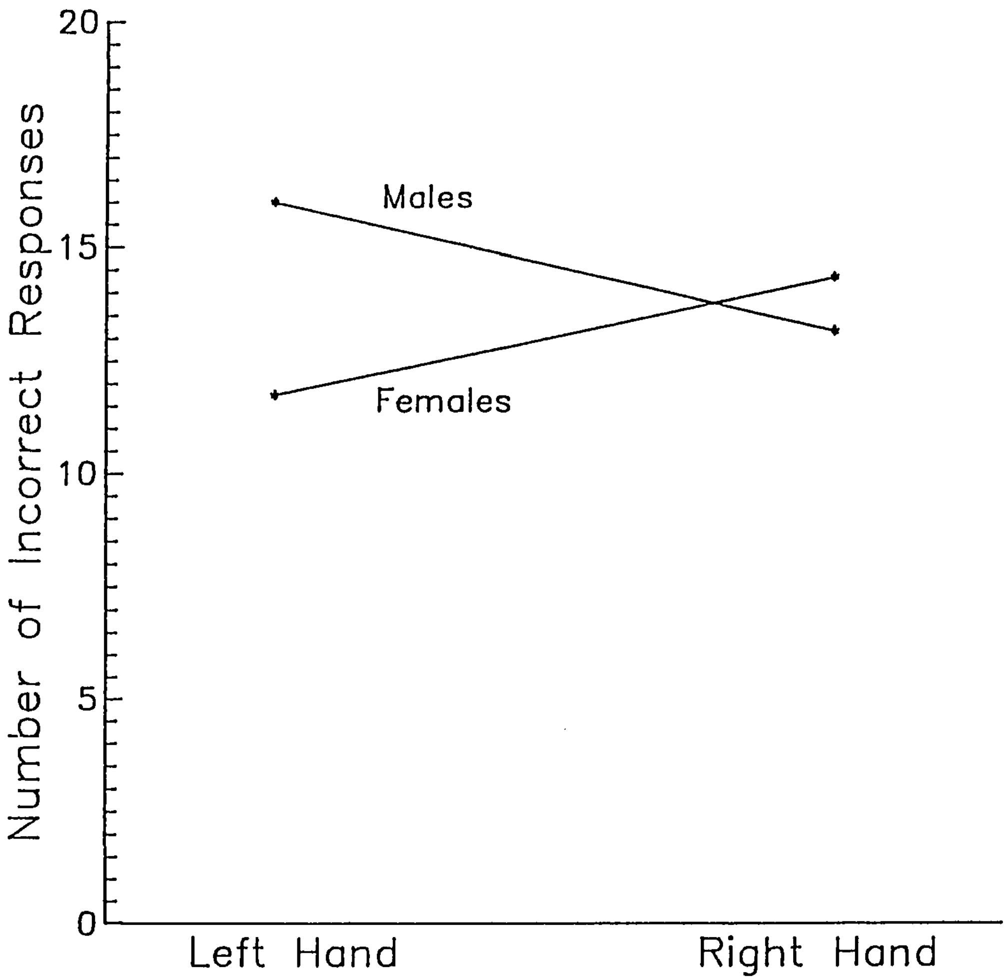


Figure 7. Number of incorrect responses on the continuous recall task as a function of gender and hand of response.

gender and hand for the number of incorrect responses.

Correlations with Dichotic Listening

The correlations between the dual task performance measures of the dichotic listening and the continuous recall task are shown in Table 15. Reaction time on the continuous recall task is significantly correlated with the reaction time measures of the dichotic listening task. The number of correct responses on the continuous recall task is positively correlated with the proportion of correct rejections on the dichotic listening task. The number of incorrect responses on the continuous recall task has a significantly positive relationship to the proportion of false alarms for the dichotic listening task. Therefore, as performance on the dichotic listening task improved so did performance on the continuous recall task.

Table 15

Correlations between the dual task performance measures of the dichotic listening and continuous recall tasks

	Continuous recall Performance Measures		
Dichotic Performance Measures	Reaction Time	Number Correct	Number Incorrect
RT Hits	0.30610*	-0.07594	-0.15777
Prop. Hits	0.13083	0.06917	0.05653
RT Correct Rej.	0.24255*	-0.03464	-0.13134
Prop. Correct Rej.	0.07453	0.22520*	-0.09881
Prop. Misses	-0.06098	0.06575	-0.00578
RT False alarms	0.23289*	-0.06815	0.00297
Prop. False alarms	-0.13073	0.09809	0.24217*
Prop. No responses	0.01431	-0.26484*	-0.09933

* $p<.05$
note: correlations based on an N of 128.

DISCUSSION

The present study investigated the effects of ear of attention, hand of response and gender on single and dual task performance. This study used verbal tasks to compare the performance predictions of the multiple resource models of Wickens (1990) and Friedman and Polson (1981). In general, the results of this study provide partial support for Wickens' Resource Model, the Task Hemispheric Integrity Principle and the Hemispheres as Resources model.

The following sections will discuss separately the results of the dichotic listening task, the antonym task and the continuous recall task as they relate to the original hypotheses, the results of previous research and the implications for future research.

Dichotic Listening Task

The results of the dependent measures of the dichotic listening task provide partial support for the Task Hemispheric Integrity Principle, some support for Wickens' Resources model and limited support of the Hemispheres as resources model. The present study did replicate the findings of previous dichotic listening studies.

Right Ear Advantage

There was support for the first hypothesis, which expected a right ear advantage for the dichotic listening task during single task trials. When subjects paid attention to their right ear during single and dual task trials they had a larger proportion of hits, faster reaction times to correct rejections, a smaller proportion of misses, and a smaller proportion of false alarms.

These results are consistent with previous dichotic listening studies which have found a right ear advantage for verbal information (Kimura, 1967; Studdert-Kennedy and Shankweiler, 1970; Bryden and Murray, 1985; Bryden, 1986). The results of the dichotic listening task replicate results obtained by Bryden and Murray (1985). They used right and left ear attention trials to dichotically presented stimuli. They found a right ear advantage for several types of verbal stimuli including stop consonants. The right ear advantage for verbal information is interpreted as evidence that the left hemisphere is superior at verbal processing. Therefore, the right ear advantage found in the present study can be interpreted to mean that the dichotic stimuli of the present study used verbal processing resources. The right ear advantage for the dichotic stimuli also provides support for the Hemispheres as Resources approach. The Hemispheres as Resources approach suggests that the left hemisphere may be more efficient at verbal information processing than the right hemisphere (Friedman and Polson, 1981). This approach predicts that there should be an advantage for right ear attention. This approach would interpret the right ear advantage as due to the superiority of the left hemisphere in processing verbal information as compared to the right hemisphere. Although the right ear advantage finding supports the Hemispheres as Resources model, critical tests of the predictions of this model rely on hand and ear interactions in the two dual task conditions. These interactions are discussed in the section describing the interaction for reaction time to correct rejections.

Gender Effects

Since males have been reported to be more lateralized than females (Bryden, 1979; McGlone, 1980), one might expect to find an interaction of ear of attention and gender for the dichotic listening task. If the males are more lateralized, they should show greater performance decrements from right to left ear attention trials. The present study did not find an interaction of gender and ear of attention for the dichotic listening task.

Consistent with the findings of the present study, Bryden and Murray (1985) did not find any sex differences in the right ear advantage to dichotically presented stop consonants. Both the present study and the study by Bryden and Murray (1985) asked subjects to pay attention to only one ear during each dichotic listening trial. Bryden (1980) noted that gender differences in dichotic listening tend to disappear under conditions of controlled attention. The present study did find gender differences in the performance of the antonym task which suggest that males are more lateralized. This finding is addressed in the section describing the results of the antonym task.

The present study did find a gender main effect where the males had faster reaction times than females for correct rejections during the dichotic listening task for single and dual task trials. There were no other differences between males and females for accuracy on the dichotic listening task. This difference is discussed in the antonym task section, because it indicates that the males may have had a task trade off between the dichotic listening and the antonym task which was different from the females.

Previous studies using a similar dichotic listening task measured the number of correct responses and did not collect reaction time measures (Hellige & Wong, 1983; Bryden & Murray, 1985; Bryden, 1986). In addition, Hellige and Wong (1983) failed to analyze or report gender differences in the dichotic listening task. Other studies have not found gender differences in dichotic listening tasks with controlled attention to the left and right ear (Bryden & Murray, 1985; Bryden, 1986).

Single Task Hand Effects

Hypothesis 2 expected superior performance on the single dichotic listening task when the hand of response was contralateral to the ear of attention. The Hemispheres as Resources Model predicts better performance when one hemisphere receives the input and processes the task while the other hemisphere controls the responses (Friedman and Polson, 1981). In this study, there were no differences between the hands and no interactions with ear of attention during single task trials on any of the nine dependent variables of the dichotic listening task.

A recent study by White and Minor (1990) did find differences between hand of response and visual field of input during single task trials. There was better performance when the information was presented to the right visual field (left hemisphere) and the subject responded with the left hand (right hemisphere control). And better performance when left visual field information (right hemisphere) was responded to by the right hand (left hemisphere control). However, these differences disappeared after 32 stimulus presentations. Each of the trials for the present study had 90 stimulus presentations so there may have been differences which did not emerge after that many presentations. In addition, the subjects had several practice trials of the dichotic listening task before beginning the experimental trials.

However, other studies have found stable interactions for hand of response and hemisphere of processing (Kee et al., 1983; Green, 1984). Green (1984) found that reaction times were faster when the hand of response was contralateral to the visual field of input for match decisions using several types of stimuli: letter shapes, letter names and cartoon faces. Performance was poorer when the same hemisphere that received the stimulus input also controlled the response hand. This interaction of visual field of input and hand of response disappeared when the processing demands of the tasks were reduced.

Dual task experiments using finger tapping have also found results which support the hand interactions predicted by the Hemispheres as Resources Model. In several of these studies, subjects tap with one hand either as a single task or concurrently with verbal tasks which did not require a manual response. The manual tapping was controlled by the contralateral hemisphere and the verbal tasks were completed by the left hemisphere. In general, right hand finger tapping was disrupted more by the verbal tasks than left hand finger tapping (Hellige & Longstreth; 1981; Hiscock, 1982; Kee et al., 1983; Friedman, et al., 1988). Poorer performance results when the left hemisphere controls both the verbal task and the manual tapping task. The consistent pattern of results found in finger tapping studies indicates that motor control of the limbs can interfere with verbal processing.

However, no interference between manual responses and cognitive processing was found in the results of the present study. It may be that the processing demands of the dichotic listening task were not large enough to illicit ear by hand interactions (Green, 1984). Green (1984) found that going from a go no-go response pattern to a choice reaction response paradigm increased the processing demands of several tasks. It would be difficult to increase the processing demand of the dichotic listening task, since the present study used a choice reaction time paradigm. Green (1984) suggests that further research is needed on the effects of stimulus processing demands for single task configurations.

General Decrements from Single to Dual Task

Wickens' Resource Model. According to Wickens' Multiple Resource Model, it was hypothesized that there should be decrements from single to dual task performance since all three tasks use the same resources. However, there should be no performance differences between the two dual task combinations since they use the same resources (Hypothesis 5). Overall, there were decrements in performance from single to dual task trials.

However, in conflict with the predictions of Wickens' resource model, several dependent measures on the dichotic listening task show differences between the antonym and continuous recall dual tasks. The proportion of hits, correct rejections and false alarms to targets in the nonattending ear varied across tasks with the largest proportions during the antonym dual task as compared to the continuous recall dual task.

These results suggest that there were different resource requirements between the dual antonym condition and the dual continuous recall condition. Wickens' resource model does not account for these performance differences. These dual task combinations, which use the same resources according to Wickens' three dimensional model, should not have performance differences. Wickens' model may be better suited to predict performance in dual task situations in which the tasks vary across the specific resource dimensions of the model.

There are several differences between the continuous recall and antonym task which could account for the performance differences. These two task differ in the type of verbal processing and the response requirements.

One possible explanation for the dual task performance differences is that the antonym and continuous recall task may have varied on resources required at the processing stage which are not accounted for in Wickens' model. Wickens defines perceptual and central processing as one pool of resources. The continuous recall and antonym tasks may have relied on different types of processing resources which resulted in different interference effects on the dichotic listening task.

The antonym match and continuous recall tasks vary in the amount of working memory resources and depth of processing required. Depth of processing is the extent to which meaningfulness is extracted from the stimulus (Eysenck & Eysenck, 1979). The antonym task requires the manipulation and comparison of semantic information. The continuous recall task loads on working memory resources by requiring subjects to maintain accurately, update and access information in working memory on a continuous basis. Compared to the continuous recall task, the antonym task requires deeper processing while the continuous recall task requires more shallow processing. In addition, the continuous recall task requires more working memory resources as compared to the antonym task, which requires retrieval of word meanings from long term memory. The present study suggests that the continuous recall task which loaded on working memory resources interfered more with a concurrent dichotic listening task than the antonym task which, required less working memory but deeper processing of verbal information.

Another explanation of the performance difference across dual task trials, is that these tasks varied in their response requirements. These tasks still require the same response process according to the verbal/manual dichotomy of response processes in Wickens model. However, the model does not take into account the frequencies of these responses. All of the tasks in the present study required the same type of manual responses but the frequency of these responses was different across the tasks. The continuous recall task had faster reaction times than the antonym task which means that the subjects made more responses to the continuous recall task during each three minute period as compared to the antonym task. It is possible that the higher frequency of responses for the continuous recall task was responsible for the poorer performance on the dichotic listening task. The difference in response frequencies may have added to the resource demands of the continuous recall task. Results of finger tapping studies suggest that motor responses can cause interference in task which require verbal processing (Hellige & Longstreth 1981; Hiscock, 1982; Kee et al., 1983; Friedman et al., 1988)

Performance for the two tasks may have been similar, if subjects maintained the same frequency of responses for the antonym task and the continuous recall task. The subjects were able to process and respond quickly to the continuous recall task during single task trials. During dual task trials, they may have allocated more resources to the continuous recall task in order to maintain or approach the speed they achieved during single task trials of the continuous recall task. However, the correlational data suggest that as performance on the continuous recall task improved so did performance on the dichotic listening task. This result suggests that the subjects did not allocate more processing or attentional resources to the continuous recall task at the expense of the dichotic listening task.

In summary, the continuous recall task used up more of the available processing resources than did the antonym task in terms of working memory and response processing. Other support for the resource demand differences between the tasks comes from the proportion of no responses. The proportion of no responses was largest during continuous recall dual task trials as compared to antonym dual task or single task trials.

Hemispheres as resources. The preceding discussion has focused on the single to dual task decrements and differences across tasks predicted by Wickens' Multiple Resource Model. The approach taken by Friedman and Polson would argue that there may be single to dual task differences, but that these decrements do not directly support or refute their model. Important tests of their model require an examination of the interactions of ear of attention, hemisphere of processing and hand of response. Therefore, single to dual task decrements must be interpreted in the context of other variables.

Moreover, the paradigms used by Friedman and Polson do not rely on effects across different types of tasks to test their model. It is difficult to make conclusions about hemispheric functioning when comparing the performance across dual task conditions which differ on many task parameters. For the present study, tests of the Hemispheres as Resources model must focus on differences within the trials of the dual antonym and dichotic listening task and on the differences within the dual continuous recall and dichotic listening trials.

Right Hand Advantage

Wickens' Model and the Task Hemispheric Integrity Principle suggest there should be a right hand advantage for verbal information during dual task conditions (Hypothesis 7). Since the left hemisphere will process the verbal task, the shortest response path is from the left hemisphere to the right hand. However, this study did not find overall superior performance when the right hand completed the dichotic listening task, antonym task or continuous recall tasks. One dependent variable (reaction time to correct rejections) did show that performance was a function of hand of response, ear of attention and task level.

One may expect right handed individuals to have a right hand advantage for different tasks because, by definition, they are right hand dominant. Right handers may find control of the right hand less demanding than the left hand. However, the present study did not find a superior right hand performance. The lack of hand differences is supported by other research which did not find superior right hand performance for right handed individuals (Green, 1984). Right hand control of a task may result in reduced processing demands that are not reflected in task performance. Also, the subjects in the present study had several practice trials and each hand was used in four of those trials. Any initial advantage for the right hand may have been counterbalanced by the conditioning of the left hand during practice trials.

Reaction Time to Correct Rejections

The reaction time to correct rejections was influenced by hand of response, ear of attention and task level for the dual continuous recall and dichotic listening combinations. There were no differences across ear of attention or hand of response during the dual task dichotic listening and antonym tasks. These results are discussed for each of the dual task combinations.

Dual antonym and dichotic listening tasks. The antonym match task is assumed to be processed by the left hemisphere (Friedman et al., 1982; Polson and Friedman, 1988). Hellige and Wong (1983) assume that for the dichotic listening task, right ear inputs will be processed by the left hemisphere while left ear inputs will be processed by the right hemisphere. The Hemispheres as Resources Model would expect poorer performance during right ear than left ear attention trials since both tasks require left hemisphere processing (Hypothesis 9). The present study found no differences in reaction time to correct rejections as a function of hand of response or ear of attention during dual task trials with the antonym task. The findings of the dual antonym conditions of the present study do not support the Hemispheres as Resources Model.

The findings of the present study do not replicate the results of previous research. Hellige and Wong (1983) used a dichotic listening task performed concurrently with a memory load task. They found poorer recognition of right ear stimuli (consonant-vowel syllables) as compared to left ear stimuli. Hellige, Block and Taylor (1988) had subjects finger tap while responding to dichotically presented consonant-vowel syllables. They found interference effects which support Friedman and Polson's model of hemispheric functioning. Studies using visual laterality techniques and concurrent verbal tasks have found larger performance decrements for right visual field stimuli as compared to left visual field stimuli (Friedman et al., 1982).

The difference between the antonym task and the verbal memory tasks used in previous research may be one reason the antonym dual task conditions did not replicate the findings of other studies. For example, one task required subjects to recite a series of nonsense words, retain those words in memory, and then recall the words aloud. Vocalization is controlled exclusively by the left hemisphere (Springer & Deutsch, 1985). Therefore, the decrements found in previous research may be due to the vocal requirements of the memory tasks. However, studies have compared tasks which require vocal and nonvocal responses, such as reading a passage aloud or silently and at the same time performing a finger tapping task (Hellige & Longstreth, 1981). These studies find that both the vocal and nonvocal verbal tasks elicit decrement patterns which indicate the verbal task required left hemisphere resources.

An alternative explanation for the lack of right ear decrements concerns the amount of processing resources used by each task. Each cerebral hemisphere is limited in its information-processing capacity so, when too many resources of one hemisphere are required, performance should decrease. Differences between left and right ear task configurations may only emerge after a certain level of processing resources have been used up by the load task.

Therefore, differences with the antonym dual task conditions may be found if processing resources required by the task were increased. One way to increase the processing demands on the antonym task would be to reduce the number of times the subjects saw the words during the testing session. The antonym task of the CTS Battery drew the words for the antonym task from a large pool of possible words. However, due to the large number of trials each subject completed, subjects sometimes saw a single word more than once during the study.

The first presentation of the word may have "primed" the subject for the word meaning which may have facilitated long term searches for that word in subsequent presentations. Becker (1976) reported that lexical decisions about words which are found in high frequency in the English language produced less interference with a choice reaction time task than decisions about low frequency words. This finding suggests that with practice, meanings for words become more accessible. Therefore, repetitions of words in the present experiment represented less of a processing demand than novel words. To increase the processing demands of long term memory search for the antonym task, it may be necessary to use novel words for each stimulus presentation a subject receives.

The performance on the dichotic listening task during dual task trials with the antonym task do not support the Hemispheres as Resources Model or the Task Hemispheric Integrity Principle. The Task Hemispheric Integrity Principle predicts superior performance during right ear attention trials with right hand responses to the dichotic task while concurrently performing the antonym task (Hypothesis 8). According to the Principle, the right ear - right hand configuration represents the shortest processing route from ear of input to hand of response.

The present study did not find an interaction for ear of attention and hand of response during dual dichotic listening and antonym conditions. Wickens assumes the dichotic listening task will be processed by the left hemisphere. If this is true, then left ear - left hand configurations represent a longer processing pathway than other arrangements. The left ear stimuli is projected to the right hemisphere, passed to the left hemisphere for processing, and then sent back to the right hemisphere so the left hand response can be made. This is a long processing path which should require longer processing time and therefore, longer reaction times.

The different task configurations between ear of attention and hand of response did not have any affect on the dependent measures of the dual dichotic listening and antonym task. Differences between task configurations may have been detected if the manual responses for the antonym task were more demanding. An increase in the frequency or complexity of antonym responses would increase the resources needed to process the task. Differences in ear of attention and hand of response may emerge once the resource demands of the antonym task are increased.

Dual continuous recall and dichotic listening. The continuous recall task, according to Polson and Friedman, is processed by the left hemisphere. During left ear attention trials the dichotic information is first projected to the right hemisphere while right ear stimuli are projected to the left hemisphere. Poorer performance should occur during right ear attention trials since both tasks rely on the left hemisphere. The Hemispheres as Resources model would predict larger single to dual task decrements on right ear attention trials, than left ear attention trials, for the dual task performance of the dichotic and continuous recall task (Hypothesis 9). This study did not find overall poorer performance during right ear attention trials of the dual continuous recall condition. The results of the dual continuous recall conditions are not consistent with the results of previous research (Friedman et al., 1982; Hellige & Wong, 1983; Hellige et al., 1988).

However, performance at each ear was also a function of hand of response. The left hand group had faster reaction times to correct rejections when attending to the left ear as compared to the right ear. The right hand group had faster reaction times when attending to the right ear as compared to the left ear.

This finding provides mixed support for Hypothesis 8 which, according to the Task Hemispheric Integrity Principle, expected better performance during right ear - right hand combinations of the dichotic listening task. This finding supports the concept that the best performance will be found when maintaining the shortest processing route from input of stimuli, to hemisphere of processing, to hand of response. However, these results do not support Wickens' position that the left hemisphere is relatively dedicated to verbal processing and will complete verbal tasks. The results suggest that the right hemisphere was able to process the dichotic listening task. It appears that both of the hemispheres were able to complete the processing requirements of the dichotic listening task. However, there was still better performance when the hemisphere that processed the task, received the input and controlled the response.

The finding that both hemispheres were able to complete the dichotic listening task provides support for the Hemispheres as Resources model which assumes that both hemispheres can complete the processing requirements of most tasks. Some studies have found that both hemispheres can complete simple verbal processing associated with perceptual decoding (Friedman et al., 1982; Hellige & Wong, 1983; Hellige et al., 1988). Studies by Hellige and Wong (1983) and Hellige et al. (1988) used the same consonant-vowel dichotic stimuli used in the present study (i.e, ga, ba, pa, da, ta). Their results suggest that the right hemisphere was able to process the dichotic stimuli presented to the left ear. Friedman et al. (1982) found evidence to indicate that the right hemisphere was partially able to process visual stimuli when the task required a physical comparison of letters or naming the letters.

It is difficult to interpret the interaction of ear of attention and hand of response in terms of the Hemispheres as Resources Model. Right hand motor movements use left hemisphere resources while left hand motor movements use right hemisphere resources. Studies which examine the effects of motor responses have subjects use only one hand at a time. For example, finger tapping studies have subjects tap with only one hand at a time (Hellige & Longstreth, 1981; Kee et al., 1983; Friedman et al., 1988). Other studies use dual task conditions which only require the use of one hand. During the dual task trials of the dichotic and continuous recall tasks, both hemispheres are controlling hand responses. When both hands are making motor responses, it is difficult to determine the differential effects of the motor responses on each hemisphere. In previous studies, researchers have controlled for the interference of manual responses by having subjects respond with both hands to the same task (Friedman et al., 1982).

It would be necessary to conduct another study, in which only one task required manual responses, to determine the interference effects of manual responses in the dual continuous recall condition. One could compare single to dual task decrements when subjects made verbal responses to the continuous recall task and responded manually to the dichotic listening task. That would allow an investigation of the effects of hand of response for the dichotic listening task in terms of the Hemispheres as Resources Model.

Reaction Time to Hits

It is interesting that the dependent variable of reaction time to hits only reflected one significant main effect. On the other hand, the dependent variable reaction time to correct rejections had a main effect of gender and a three way interaction of task level, hand of response and ear of attention. What is the difference between the subject's 'yes' responses (hits) and the 'no' responses (correct rejections)? There is a correlation of .617 between reaction time to hits and correct rejections. This strong relationship does not explain the different effects found with reaction times to hits and correct rejections.

One reason for the differences found between these measures is that the reaction time to correct rejections may be a more stable measure. During each three minute trial there were 15 possible hits and 75 possible correct rejections for the subjects to make. For each trial, median reaction time for correct rejections was determined based on a larger pool of reaction time measures than the reaction time to hits. The reaction time to correct rejections may be more representative of the whole task since there are more possible correct rejections than hits. Therefore, one can be more confident of conclusions drawn from correct rejections measures than conclusions based on measures of hits.

Reaction Time to False Alarms

There was a four-way interaction of gender, hand of response, task level and ear of attention for the reaction time to false alarms. These results do not show a clear pattern that is easily interpreted. A false alarm occurs when the target is not present in the attending ear and the subject indicates that the target is present. What happens when a subject makes a false alarm? For this specific dichotic listening task, a subject could be responding to a distractor or to the presence of the target in the nonattending ear. During the dual task conditions subjects made an average of 13.28 false alarms per trial. Approximately half of these false alarms (6.72) were false alarms to targets in the nonattending ear and the remaining were false alarms to distractors. Thus, the median reaction time to false alarms represents two separate types of responses that the subject could be making. In addition, the number of false alarms varied widely across subjects and conditions.

No Responses

There was a three way interaction for the proportion of no responses on the dichotic listening task. This interaction was accounted for by the left hand group who, during the continuous recall task, had fewer no responses when listening to the left ear than to the right ear. It is difficult to interpret what a no response on the dichotic listening task means in terms of each of the ear and hand conditions.

When subjects do not respond to a task, one can assume that they are not paying attention to the task. Therefore, the dependent variable of proportion of no responses can only provide very gross information about the task conditions. In general, subjects had the most no responses during the continuous recall task, followed by the antonym task and then the single task trials. The proportion of no responses on the dichotic listening task indicates the relative processing differences of the task levels. This result indicates that the continuous recall task required more processing resources than the concurrent performance of the antonym and dichotic listening tasks.

Antonym Match Task

The results of the dependent measures of the antonym task do not support the models of Friedman and Polson (1981) or Wickens (1980). Results of the antonym task do support gender differences in verbal processing and gender differences in lateralization.

Hand effects

There were no hand effects in the dependent measures of the antonym task during single or dual task trials. This finding does not support the Hemispheres as Resources Model, which would predict superior left hand performance on single task trials of the antonym task (Hypothesis 3). During right hand trials, processing of the antonym task and control of responses is controlled by the left hemisphere. The Hemispheres as Resources Model predicts better performance when the two hemispheres share processing requirements of the task, which would happen on left hand trials of the antonym task.

As discussed previously, studies have found that manual responses to a task can interfere with the processing of that task if the same hemisphere processes and responds to the task (Green, 1984; White & Minor, 1990). The resources required to process and respond to the antonym task may not have exceeded the capacity of one hemisphere. Therefore, the left hemisphere may have been able to process and respond to the task without performance decrements during right ear attention trials.

The lack of hand differences during the dual task trials of the antonym task does not support the Task Hemispheric Integrity Principle. It was hypothesized that there would be better performance during right hand control of the antonym task (Hypothesis 7). Since the antonym task is processed by the left hemisphere, the shortest processing route is from the left hemisphere to the right hand.

The antonym task was presented to the center of the visual field. It is assumed that the task was processed by the left hemisphere. The lack of hand differences for both single and dual task conditions could be explained if, the right hemisphere processed some of the antonym task. A better test of the effect of hand of response requires lateral presentation of the antonym task (Polson & Friedman, 1988). If the antonym task were shown in the right visual field, one could be more certain that the left hemisphere was receiving and processing the task.

Gender Effects

Based on previous research, it was hypothesized that females would have better performance on the antonym task (Hypothesis 4). The gender differences found for the antonym task support this hypothesis. The females had faster reaction times and more correct responses than males. This finding is supported by other literature which finds females superior in tasks of verbal fluency, spelling, perceptual speed and finger dexterity (Maccoby & Jacklin, 1974; Wittig & Peterson, 1979).

An alternative explanation of the gender differences on the antonym task is that the males may have allocated resources differently than the females. The females had faster reaction times on the antonym task and males had faster times to correct rejections on the dichotic listening task. These differences could be interpreted to mean that the males allocated more resources to the dichotic listening task, while the females allocated more resources to the antonym task.

Other evidence suggests that there was no reaction time or performance tradeoff between the two tasks. There were no significant correlations between the antonym reaction time and the reaction time measures of the dichotic listening task and, no significant correlations for these variables by gender. This suggests that reaction time on the antonym task is not directly related to reaction time on the dichotic listening task. There were positive correlations between performance measures on the antonym task and the proportion of hits and correct rejections on the dichotic listening task. As performance on one task increased, the performance on the other task also increased. But, correlational data do not support the interpretation that the males paid more attention to the dichotic listening task at the expense of the antonym task.

Further evidence of the difference between males and females, was found in the gender by task level interaction for the number of incorrect responses on the antonym task. Males had more incorrect responses on the antonym task during right ear attention trials than females (see Figure 6). Wickens' Resource Model, the Task Hemispheric Integrity Principle and the Hemispheres as Resources Model do not address the moderating effects of gender on information processing. Many of the previous studies of hemispheric differences by both groups have tested only male subjects (cf. Wickens, Mountford & Schreiner, 1981; Friedman et al., 1982; Green, 1984; Carswell & Wickens, 1985; Herdman & Friedman, 1985; Friedman, et al., 1988). One reason studies rely on male subjects is that males are more lateralized so one can expect to find more hemispheric differences. In addition, studies that have used both genders, either have not analyzed for gender differences or do not report those differences (Hellige & Wong, 1983; Wickens & Liu, 1988).

The interaction of ear of attention and gender can be explained in terms of the laterality differences found between males and females. Previous studies have found that males are more lateralized than females (McGlone, 1980). In other words, males have to rely more on their left hemisphere for verbal processing than females. During right ear attention trials, both the dichotic listening task and the antonym task are processed by the left hemisphere. Males have to rely more on the left hemisphere to complete both tasks than do females. Females can share the processing requirements of these tasks with the right hemisphere. Therefore, males have more performance decrements during right ear attention trials than do the females.

Single to Dual Task Decrements

Based on Wickens' Resource Model, it was hypothesized that there would be decrements on the antonym task from single to dual task trials (Hypothesis 6). There were single to dual task decrements with faster reaction times and more correct responses during the single task trials, as compared to dual left ear attention or dual right ear attention trials. Both the antonym task and the dichotic listening task use the same resources on each of the three dimensions of Wickens' Multiple Resource Model (i.e., early processing, verbal processing and manual responses). This model predicts that tasks which use the same resources should interfere with one another. The single to dual task decrements on the antonym task support Wickens' Model.

Continuous Recall Task

The results of the continuous recall task do not support the Hemispheres as Resources Model or the Task Hemispheric Integrity Principle. The single to dual task decrements of the continuous recall task provide limited support for Wickens' Resource Model.

Hand Effects

The Hemispheres as Resources Model predicted better left hand performance on the single task trials of the continuous recall task (Hypothesis 3). This hypothesis was not supported, as there were no hand differences during single task trials of the continuous recall task. Previous studies have found better performance when one hemisphere processed the task and the other controlled the responses (Green, 1984; White & Minor, 1990). During single task trials of the continuous recall task, subjects were able to achieve almost flawless performance. There was very little variation in performance across left and right hand trials and across subjects. This indicates that when the left hemisphere processed the continuous recall task, there was enough spare resources to complete manual responses without decrements in performance.

Based on the Task Hemispheric Integrity Principle, it was hypothesized that there would be a right hand advantage for responding to the continuous recall task during dual task trials (Hypothesis 7). The Principle assumes that the left hemisphere is dedicated to verbal processing while, the right hemisphere completes spatial processing. The results of the continuous recall task do not support this hypothesis. There were no performance differences between left and right hand responding of the continuous recall task for dual task trials. This result is not consistent with studies that have found superior performance when the hemisphere which completes task processing also controls the response hand (Wickens, Vidulich & Sandry-Garza, 1984).

However, the continuous recall task was presented to the center of the visual field, which may account for the lack of hand differences during single and dual task trials. It may be necessary to lateralize the presentation of this task to be more certain that the left hemisphere receives and processes the task (Polson & Friedman, 1988). The ear by hand interaction of the dichotic listening task, during dual task trials with the continuous recall task, suggests that the continuous recall task was processed by the left hemisphere.

Previous studies have presented a memory load task to the center of the visual field while the concurrent task is presented laterally to the subject (Friedman et al., 1982; Hellige & Wong, 1983). These studies find task interference effects with the centrally presented task. Contrary to the present experiment, these studies have a rigorous selection procedure for their subjects which includes testing for right visual field dominance. Using subjects with a right visual field dominance for verbal information, increases the probability that the subjects are left hemisphere dominant for verbal processing.

Gender Effects

Based on previous research, it was hypothesized that females would have better performance than the males on the continuous recall task (Hypothesis 4). The results do not support this hypothesis. There were no overall differences between males and females on the performance of this task. The results of previous research have been mixed, and gender differences have been found only for some verbal tasks. Previous studies have found that females outperform males in tests of verbal fluency (Maccoby & Jacklin, 1974; Wittig & Peterson, 1979; Harshman, Hampson & Berenbaum, 1983). The continuous recall task required the resources of working memory and did not tap the verbal fluency of the subjects. On the antonym task, the subjects were required to search for the meanings of words in long term memory. The females did outperform the males on the antonym task.

However, across single and dual task trials, the effect of hand of response was mediated by the gender of the subjects. When the subjects were using their left hand to complete the continuous recall task, males had more incorrect responses than females. Left hand response males committed an average of 16 errors per trial while left hand response females committed 11.73 errors per trial. This was the only difference found. This result indicates females were able to maintain a better level of performance than the males, when the left hemisphere processed the continuous recall task and the right hemisphere controlled the responses. This result cannot be interpreted in terms of past research or the multiple resource models.

Single to Dual Task Decrements

Based on Wickens' Resource Model, it was hypothesized that there would be decrements on the continuous recall task from single to dual task performance (Hypothesis 6). The results of the continuous recall task support this hypothesis. Performance on the continuous recall task deteriorated when it was time shared with the dichotic listening task. Both the continuous recall task and the dichotic listening task require the same resources according to Wickens' three dimensional model (i.e., early processing, verbal processing, and manual responses). Tasks which require the same resources on one or more dimensions of the model, should show larger single to dual task decrements than tasks which require different resources on each dimension (Wickens, 1980).

The Hemispheres as Resources Model would predict larger decrements during right ear attention trials of the continuous recall dual task than left ear attention trials (Hypothesis 9). The results of the continuous recall task do not support this hypothesis. There were general decrements from single to dual task performance but, no differences between left and right ear attention trials on the continuous recall task. This result is surprising, because the task was designed to place heavy demands on working memory resources. Tasks which load heavily on working memory in other studies, have found patterns of decrements which support the Hemispheres as Resources Model. The continuous recall task differs in some ways from the nonsense task which may account for the divergent findings. The continuous recall task loads on working memory resources by requiring subjects to maintain, update, and access information in working memory in an overlapping pattern. The nonsense memory tasks require the reading, retention and vocal recall of a stimulus series. Tasks which require vocalization have been found to show larger interference effects than tasks without vocalization (Hellige & Longstreth, 1981). Further research is needed on the parameters of verbal tasks which influence the pattern of dual task decrements.

Summary

Wickens' three-dimensional resource model predicts that tasks which use the same resources should cause more interference than tasks which rely on different resources. The present study found some support for this model. The three tasks used in the study all used the same resources and, all showed decrements from single to dual task trials. However, Wickens' model was not able to account for the performance differences across the two dual task combinations which use the same resources. Wickens' Resource Model is better suited to predict performance for dual task combinations which require different resources pools.

Although the single to dual task decrements can be accounted for by Wickens' Model, it is important to note that these decrements can be accounted for by the single resource models (Kahneman, 1973). In general, the single resource models hypothesize the existence of one pool of mental resources for which all tasks compete. The tasks of the present study do compete for that one pool of resources so, they should show single to dual task decrements.

The present study provides partial support for the Task Hemispheric Integrity Principle. There was support for maintaining the shortest processing route from input of information to hand of response. However, there was less support for Wickens' position that information that is incompatible with a hemisphere's specialization must be sent to the other hemisphere for processing. During the dual continuous recall conditions, it appeared the right hemisphere (which is said to be dedicated to spatial processing) was able to identify verbal dichotic stimuli presented to the left ear.

This study found limited support for the Hemispheres as Resources Model. Processing of the dichotic stimuli by the right hemisphere supports Friedman and Polsons' (1981) premise that both hemispheres can process most tasks using their own respective resources. Previous studies have found that the right hemisphere can complete simple verbal processing associated with perceptual decoding, such as the physical identity of letters (Friedman et al., 1982) and identification of consonant - vowel dichotic stimuli (Hellige & Wong, 1983; Hellige et al., 1988).

This study does not support Friedman and Polsons' premise that each cerebral hemisphere represents qualitatively different resources. In contrast to previous studies, motor responses were not found to interfere with cognitive processing on single task trials. In addition, there were no differential interference effects of verbal processing on left and right ear attention trials.

Therefore, the effects found in previous research on Friedman and Polsons (1981) model did not generalize to other types of verbal processing tasks. The tasks of the present study differ from the verbal memory load tasks used by previous studies. Further research is needed on the parameters of verbal task which show lateralized interference effects on a concurrent task.

The present study did find some gender differences which support previous research. The better performance of the females on the antonym task is consistent with research which has found females to be superior in tests of verbal fluency (Maccoby & Jacklin, 1974; Wittig & Peterson, 1979). The interaction of ear of attention and gender, found on the antonym task, indicates males may be more lateralized than females (McGlone, 1980). The models of Wickens (1980) and Friedman and Polson (1981) do not account for the moderating effects of gender on single or dual task performance. Many of the previous studies by these groups used only male subjects. Future tests of these models should use both males and females as subjects and report gender differences.

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APPENDIX A

Task Instructions: Dichotic Listening

TASK INSTRUCTIONS: DICHOTIC LISTENING

For the dichotic listening task you will hear a series of 2 letter words called stop consonants (for example, ga, ba, ca, pa, ta, da). They will be presented over this set of headphones. A different stop consonant will be presented to your left and right ear at the same time. Listen for the target sound "ca".

Each trial will last three minutes. For each trial you will focus your attention on just the sounds presented in one ear. For example, for some of the trials you will pay attention to the stimuli presented in your left ear. When you hear a pair of consonants you must listen, decide if you heard the sound "Ca" in your left ear and respond as quickly as possible by pushing the lever to the "yes" position if you heard the target and to the "no" position if you did not hear the target in your left ear. For each pair of stimuli your response will be based on whether the target was or was not present in your left ear only. You will hear a new pair of stop consonants every 1.5 seconds. The object of this task is to respond as quickly as possible to the presence or absence of the target consonant in the attending ear. At the end of the tape please wait for instructions regarding your next task. Do you have any questions?

APPENDIX B

Task Instructions: Antonym Match

TASK INSTRUCTIONS: ANTONYM MATCH

The antonym match task requires you to classify pairs of words on the basis of their meaning. A pair of words are presented together on the screen, and you must decide whether the words are opposite in meaning or not. For example, the words LAWFUL - CRIMINAL have the opposite meaning and, therefore, you would push the button labeled "opposite". The words ETERNAL - NONSENSE are not opposite in meaning so you would push the button labeled "not opposite".

This task is performed in 3-minute trial periods. You start the data collection when you are ready by pressing the response lever in either direction. Stimuli will appear one pair at a time, and you should attempt to respond as quickly and accurately as possible. As soon as you enter a response, the next problem will appear. Respond as quickly as you can when answering each item, but if you find yourself making errors from going too fast, slow down. You should try to get every item right.

Three minutes after you press the lever to start the trial, the task will automatically stop, and the screen will go blank. At the end of the task, please wait for instructions regarding your next task. Do you have any questions?

APPENDIX C

Task Instructions: Continuous Recall

TASK INSTRUCTIONS: CONTINUOUS RECALL

In the continuous recall task, you will see a series of one digit number pairs, one number appearing above the other. Only one pair of numbers is presented on the screen at a time. Your task is to memorize the bottom number, and decide whether the top number is the same as the bottom number that you memorized two screens earlier. For example, if the stimuli were:

Screen 1	Screen 2	Screen 3	Screen 4
0	0	7	7
-	-	-	-
4	7	2	1

the correct responses would be screen 1 - push lever to either the "same" or "different" position (neither response is incorrect because there is nothing one screen back from the first screen; press either key when you have memorized the bottom number); Screen 2 - push lever to "different" since the "0" on top does not match the 4 on the bottom of screen 1; Screen 3 - push lever to "same" since the "7" on top matches the "7" on the bottom of screen 2; Screen 4 - push lever to "different" since the "7" on the top does not match the 2 on the bottom of screen 3.

In order to successfully perform this task, you will have to do two things every time the screen changes. First, you must memorize the bottom number, and then you must indicate whether the top number on the current screen is the same or different than the bottom number on the previous screen. Remember that you must memorize the bottom number berfore you respond, because a new screen will appear when you press a key, and the information will be lost. Also, keep in mind that the response to the first screen does not matter.

When I tell you to do so, you will be starting each data collection period by pressing the lever in either direction. You should try to repond as quickly and accurately as possible. When you enter a response, the next screen will immediately be displayed. If you find yourself making erroneous responses from trying to go too fast, slow down. However, do not take any more time than is necessary to remember the bottom number and correctly respond to the top number.

At the end of the 3-minute period, the task will stop and the screen will go blank. At the end of the task please wait for instructions regarding your next task. Do you have any questions?

APPENDIX D

Dichotic Listening Task Means

DICHOTIC LISTENING MEANS

RT HIT = REACTION TIME FOR HITS
P(HIT) = PROPORTION OF HITS
RT CR = REACTION TIME FOR CORRECT REJECTIONS
P(CR) = PROPORTION OF CORRECT REJECTIONS
P(MISS) = PROPORTION OF MISSES
P(FA TAR) = PROPORTION OF FALSE ALARMS TO TARGETS IN THE NONATTENDING EAR
RT FA = REACTION TIME TO FALSE ALARMS
P(FA) = PROPORTION OF FALSE ALARMS
P(NO RESPONSES) = PROPORTION OF NO RESPONSES

HAND	N	RT HIT	P(HIT)	RT CR	P(CR)
RIGHT	192	802.192	0.696	852.484	0.626
LEFT	192	786.817	0.694	839.604	0.602

HAND	N	P(MISS)	P(FA TAR)	RT FA	P(FA)
RIGHT	192	0.149	0.48750000	847.406	0.191
LEFT	192	0.132	0.51527778	836.531	0.181

HAND	N	P(NO RESPONSES)
RIGHT	192	0.177
LEFT	192	0.208

TASK	N	RT HIT	P(HIT)	RT CR	P(CR)
SINGLE	128	672.140	0.902	686.484	0.776
DUAL ANT	128	856.539	0.630	927.343	0.573
DUAL CR	128	854.835	0.553	924.304	0.492

TASK	N	P(MISS)	P(FA TAR)	RT FA	P(FA)
SINGLE	128	0.0833	0.6083	736.710	0.2054
DUAL ANT	128	0.1708	0.4843	911.820	0.1817
DUAL CR	128	0.1692	0.4114	877.375	0.1722

TASK	N	P(NO RESPONSES)
SINGLE	128	0.0165
DUAL ANT	128	0.2364
DUAL CR	128	0.3256

EAR	N	RT HIT	P(HIT)	RT CR	P(CR)
RIGHT	192	789.979	0.7520	838.312	0.6173
LEFT	192	799.031	0.6388	853.776	0.6108

EAR	N	P(MISS)	P(FA TARG)	RT FA	P(FA)
RIGHT	192	0.0892	0.4454	841.197	0.1781
LEFT	192	0.1930	0.5572	842.739	0.1947

EAR	N	P(NO RESPONSES)
RIGHT	192	0.1960
LEFT	192	0.1896

GENDER	N	RT HIT	P(HIT)	RT CR	P(CR)
MALE	192	778.427	0.6961	825.140	0.6187
FEMALE	192	810.583	0.6947	866.947	0.6094

GENDER	N	P(MISS)	P(FA TARG)	RT FA	P(FA)
MALE	192	0.1461	0.5204	830.718	0.1919
FEMALE	192	0.1361	0.4822	853.218	0.1810

GENDER	N	P(NO RESPONSES)
MALE	192	0.1825
FEMALE	192	0.2032

HA	TASK	N	RT HIT	P(HIT)	RT CR	P(CR)
R	S	64	679.906	0.8968	690.593	0.7712
R	DA	64	856.484	0.6552	918.750	0.5945
R	DCR	64	870.187	0.5385	948.109	0.5127
L	S	64	664.375	0.9083	682.375	0.7820
L	DA	64	856.593	0.6062	935.937	0.5525
L	DCR	64	839.484	0.5677	900.500	0.4714

HA	TASK	N	P(MISS)	P(FA TAR)	RT FA	P(FA)
R	S	64	0.0895	0.5989	738.796	0.2147
R	DA	64	0.1666	0.4729	928.109	0.1870
R	DCR	64	0.1927	0.3906	875.312	0.1716
L	S	64	0.0770	0.6177	734.625	0.1960
L	DA	64	0.1750	0.4958	895.531	0.1764
L	DCR	64	0.1458	0.4322	879.437	0.1729

HA	TASK	N	P(NO RESPONSES)
R	S	64	0.01302
R	DA	64	0.21111
R	DCR	64	0.30711
L	S	64	0.02013
L	DA	64	0.26180
L	DCR	64	0.34409

TASK	EAR	N	RT HIT	P(HIT)	RT CR	P(CR)
S	RIGHT	64	658.218	0.9510	678.140	0.7885
S	LEFT	64	686.062	0.8541	694.828	0.7647
DA	R	64	847.078	0.6916	917.015	0.5754
DA	L	64	866.000	0.5697	937.671	0.5716
DCR	R	64	864.640	0.6135	919.781	0.4881
DCR	L	64	845.031	0.4927	928.828	0.4960

TASK	EAR	N	P(MISS)	P(FA TAR)	RT FA	P(FA)
S	R	64	0.0385	0.5531	729.421	0.1943
S	L	64	0.1281	0.6635	744.000	0.2164
DA	R	64	0.1062	0.4229	898.031	0.1714
DA	L	64	0.2354	0.5458	925.609	0.1920
DCR	R	64	0.1229	0.3604	896.140	0.1687
DCR	L	64	0.2156	0.4625	858.609	0.1758

TASK	EAR	N	P(NO RESPONSES)
S	R	64	0.01527
S	L	64	0.01788
DA	R	64	0.24357
DA	L	64	0.22934
DCR	R	64	0.32934
DCR	L	64	0.32187

HAND	EAR	N	RT HIT	P(HIT)	RT CR	P(CR)
R	R	96	798.333	0.7645	838.645	0.6329
R	L	96	806.052	0.6291	866.322	0.6194
L	R	96	781.625	0.7395	837.979	0.6018
L	L	96	792.010	0.6486	841.229	0.6022

HAND	EAR	N	P(MISS)	P(FA TAR)	CR FA	P(FA)
R	R	96	0.0909	0.4305	847.604	0.1834
R	L	96	0.2083	0.5444	847.208	0.1988
L	R	96	0.0875	0.4604	834.791	0.1729
L	L	96	0.1777	0.5701	838.270	0.1906

HAND	EAR	N	P(NO RESPONSES)
R	R	96	0.17523
R	L	96	0.17893
L	R	96	0.21689
L	L	96	0.20046

HAND	GENDER	N	RT HIT	P(HIT)	RT CR	P(CR)
R	MALE	96	791.875	0.6847	841.197	0.6279
R	FEMALE	96	812.510	0.7090	863.770	0.6244
L	MALE	96	764.979	0.7076	809.083	0.6095
L	FEMALE	96	808.656	0.6805	870.125	0.5944

HAND	GENDER	N	P(MISS)	P(FA TAR)	RT FA	P(FA)
R	M	96	0.1597	0.4986	849.739	0.1980
R	F	96	0.1395	0.4763	845.072	0.1843
L	M	96	0.1326	0.5423	811.697	0.1858
L	F	96	0.1326	0.4881	861.364	0.1777

HAND	GENDER	N	P(NO RESPONSES)
R	M	96	0.1699
R	F	96	0.1842
L	M	96	0.1951
L	F	96	0.2222

SEX	TASK	N	RT HIT	P(HIT)	RT CR	P(CR)
M	S	64	663.078	0.9093	678.437	0.7675
M	DA	64	846.125	0.6291	909.859	0.5791
M	DCR	64	826.078	0.5500	887.125	0.5095
F	S	64	681.203	0.8958	694.531	0.7858
F	DA	64	866.953	0.6322	944.828	0.5679
F	DCR	64	883.593	0.5562	961.484	0.4745

SEX	TASK	N	P(MISS)	P(FA TAR)	RT FA	P(FA)
M	S	64	0.0750	0.6395	719.968	0.2104
M	DA	64	0.1822	0.4739	901.093	0.1808
M	DCR	64	0.1812	0.4479	871.093	0.1845
F	S	64	0.0916	0.5770	753.453	0.2004
F	DA	64	0.1593	0.4947	922.546	0.1827
F	DCR	64	0.1572	0.3750	883.656	0.1600

SEX	TASK	N	P(NO RESPONSES)
M	S	64	0.0194
M	DA	64	0.2286
M	DCR	64	0.2994
F	S	64	0.0137
F	DA	64	0.2442
F	DCR	64	0.3517

SEX	EAR	N	RT HIT	P(HIT)	RT CR	P(CR)
M	R	96	772.041	0.7395	817.156	0.6225
M	L	96	784.812	0.6527	833.125	0.6150
F	R	96	807.916	0.7645	859.468	0.6122
F	L	96	813.250	0.6250	874.427	0.6066

SEX	EAR	N	P(MISS)	P(FA TAR)	RT FA	P(FA)
M	R	96	0.1055	0.4583	843.604	0.1829
M	L	96	0.1868	0.5826	817.833	0.2009
F	R	96	0.0729	0.4326	838.791	0.1734
F	L	96	0.1993	0.5319	867.645	0.1886

SEX	EAR	N	P(NO RESPONSES)
M	R	96	0.1870
M	L	96	0.1780
F	R	96	0.2050
F	L	96	0.2013

HAND	TASK	EAR	N	RT HIT	P(HIT)	RT CR
R	S	R	32	675.375	0.9583	686.843
R	S	L	32	684.437	0.8354	694.343
R	DA	R	32	840.093	0.7166	906.218
R	DA	L	32	872.875	0.5937	931.281
R	DCR	R	32	879.531	0.6187	922.875
R	DCR	L	32	860.843	0.4583	973.343
L	S	R	32	641.062	0.9437	669.437
L	S	L	32	687.687	0.8729	695.312
L	DA	R	32	854.062	0.6666	927.812
L	DA	L	32	859.125	0.5458	944.062
L	DCR	R	32	849.750	0.6083	916.687
L	DCR	L	32	829.218	0.5270	884.312

HAND	TASK	EAR	N	P(CR)	P(MISS)	P(FA TAR)
R	S	R	32	0.7829	0.0270	0.5354
R	S	L	32	0.7595	0.1520	0.6625
R	DA	R	32	0.5958	0.1062	0.4250
R	DA	L	32	0.5933	0.2270	0.5208
R	DCR	R	32	0.5200	0.1395	0.3312
R	DCR	L	32	0.5054	0.2458	0.4500
L	S	R	32	0.7941	0.0500	0.5708
L	S	L	32	0.7700	0.1041	0.6645
L	DA	R	32	0.5550	0.1062	0.4208
L	DA	L	32	0.5500	0.2437	0.5708
L	DCR	R	32	0.4562	0.1062	0.3895
L	DCR	L	32	0.4866	0.1854	0.4750

HAND	TASK	EAR	N	RT FA	P(FA)	P(NO RESPONSES)
R	S	R	32	734.656	0.2000	0.01527
R	S	L	32	742.937	0.2295	0.01076
R	DA	R	32	900.937	0.1791	0.21388
R	DA	L	32	955.281	0.1950	0.20833
R	DCR	R	32	907.218	0.1712	0.29652
R	DCR	L	32	843.406	0.1720	0.31770
L	S	R	32	724.187	0.1887	0.01527
L	S	L	32	745.062	0.2033	0.02500
L	DA	R	32	895.125	0.1637	0.27326
L	DA	L	32	895.937	0.1891	0.25034
L	DCR	R	32	885.062	0.1662	0.36215
L	DCR	L	32	873.812	0.1795	0.32604

HAND	SEX	TASK	N	RT HIT	P(HIT)	RT CR
R	M	S	32	690.093	0.8875	704.656
R	M	DA	32	837.625	0.6375	905.562
R	M	DCR	32	847.906	0.5291	913.375
R	F	S	32	669.718	0.9062	676.531
R	F	DA	32	875.343	0.6729	931.937
R	F	DCR	32	892.468	0.5479	982.843
L	M	S	32	636.062	0.9312	652.218
L	M	DA	32	854.625	0.6208	914.156
L	M	DCR	32	804.250	0.5708	860.875
L	F	S	32	692.687	0.8854	712.531
L	F	DA	32	858.562	0.5916	957.718
L	F	DCR	32	874.718	0.5645	940.125

HAND	SEX	TASK	N	P(CR)	P(MISS)	P(FA TAR)
R	M	S	32	0.7604	0.09166	0.63125
R	M	DA	32	0.5916	0.18333	0.45625
R	M	DCR	32	0.5316	0.20416	0.40833
R	F	S	32	0.7820	0.08750	0.56666
R	F	DA	32	0.5975	0.15000	0.48958
R	F	DCR	32	0.4937	0.18125	0.37291
L	M	S	32	0.7745	0.05833	0.64791
L	M	DA	32	0.5666	0.18125	0.49166
L	M	DCR	32	0.4875	0.15833	0.48750
L	F	S	32	0.7895	0.09583	0.58750
L	F	DA	32	0.5383	0.16875	0.50000
L	F	DCR	32	0.4554	0.13333	0.37708

HAND	SEX	TASK	N	RT FA	P(FA)	P(NO RESPONSES)
R	M	S	32	728.468	0.2208	0.01701
R	M	DA	32	934.562	0.1891	0.21180
R	M	DCR	32	886.187	0.1841	0.28090
R	F	S	32	749.125	0.2087	0.00902
R	F	DA	32	921.656	0.1850	0.21041
R	F	DCR	32	864.437	0.1591	0.33333
L	M	S	32	711.468	0.2000	0.02187
L	M	DA	32	867.625	0.1725	0.24548
L	M	DCR	32	856.000	0.1850	0.31805
L	F	S	32	757.781	0.1920	0.01840
L	F	DA	32	923.437	0.1804	0.27812
L	F	DCR	32	902.875	0.1608	0.37013

SEX	TASK	EAR	N	RT HIT	P(HIT)	RT CR
M	S	R	32	647.093	0.93750	671.218
M	S	L	32	679.062	0.88125	685.656
M	DA	R	32	822.156	0.66875	892.656
M	DA	L	32	870.093	0.58958	927.062
M	DCR	R	32	846.875	0.61250	887.593
M	DCR	L	32	805.281	0.48750	886.656
F	S	R	32	669.343	0.96458	685.062
F	S	L	32	693.062	0.82708	704.000
F	DA	R	32	872.000	0.71458	941.375
F	DA	L	32	861.906	0.55000	948.281
F	DCR	R	32	882.406	0.61458	951.968
F	DCR	L	32	884.781	0.49791	971.000

SEX	TASK	EAR	N	P(CR)	P(MISS)	P(FA TAR)
M	S	R	32	0.78666	0.04375	0.57291
M	S	L	32	0.74833	0.10625	0.70625
M	DA	R	32	0.57833	0.13125	0.40416
M	DA	L	32	0.58000	0.23333	0.54375
M	DCR	R	32	0.50250	0.14166	0.39791
M	DCR	L	32	0.51666	0.22083	0.49791
F	S	R	32	0.79041	0.03333	0.53333
F	S	L	32	0.78125	0.15000	0.62083
F	DA	R	32	0.57250	0.08125	0.44166
F	DA	L	32	0.56333	0.23750	0.54791
F	DCR	R	32	0.47375	0.10416	0.32291
F	DCR	L	32	0.47541	0.21041	0.42708

SEX	L	EA	N	RT FA	P(FA)	P(NO RESPONSES)
M	S	R	32	715.625	0.19250	0.01875
M	S	L	32	724.312	0.22833	0.02013
M	DA	R	32	899.281	0.17291	0.23993
M	DA	L	32	902.906	0.18875	0.21736
M	DCR	R	32	915.906	0.18333	0.30243
M	DCR	L	32	826.281	0.18583	0.29652
F	S	R	32	743.218	0.19625	0.01180
F	S	L	32	763.687	0.20458	0.01562
F	DA	R	32	896.781	0.17000	0.24722
F	DA	L	32	948.312	0.19541	0.24131
F	DCR	R	32	876.375	0.15416	0.35625
F	DCR	L	32	890:937	0.16583	0.34722

HAND	SEX	TASK	EAR	N	RT HIT	P(HIT)	RT CR
R	M	S	R	16	687.312	0.92916	703.125
R	M	S	L	16	692.875	0.84583	706.187
R	M	DA	R	16	812.687	0.69583	878.125
R	M	DA	L	16	862.562	0.57916	933.000
R	M	DCR	R	16	864.000	0.62500	886.812
R	M	DCR	L	16	831.812	0.43333	939.937
R	F	S	R	16	663.437	0.98750	670.562
R	F	S	L	16	676.000	0.82500	682.500
R	F	DA	R	16	867.500	0.73750	934.312
R	F	DA	L	16	883.187	0.60833	929.562
R	F	DCR	R	16	895.062	0.61250	958.937
R	F	DCR	L	16	889.875	0.48333	1006.750
L	M	S	R	16	606.875	0.94583	639.312
L	M	S	L	16	665.250	0.91666	665.125
L	M	DA	R	16	831.625	0.64166	907.187
L	M	DA	L	16	877.625	0.60000	921.125
L	M	DCR	R	16	829.750	0.60000	888.375
L	M	DCR	L	16	778.750	0.54166	833.375
L	F	S	R	16	675.250	0.94166	699.562
L	F	S	L	16	710.125	0.82916	725.500
L	F	DA	R	16	876.500	0.69166	948.437

L	F	DA	L	16	840.625	0.49166	967.000
L	F	DCR	R	16	869.750	0.61666	945.000
L	F	DCR	L	16	879.687	0.51250	935.250

HAND	SEX	TASK	EAR	N	P(CR)	P(MISS)	P(FA TAR)
R	M	S	R	16	0.78250	0.04583	0.54583
R	M	S	L	16	0.73833	0.13750	0.71666
R	M	DA	R	16	0.58583	0.12916	0.40416
R	M	DA	L	16	0.59750	0.23750	0.50833
R	M	DCR	R	16	0.52583	0.16250	0.36250
R	M	DCR	L	16	0.53750	0.24583	0.45416
R	F	S	R	16	0.78333	0.00833	0.52500
R	F	S	L	16	0.78083	0.16666	0.60833
R	F	DA	R	16	0.60583	0.08333	0.44583
R	F	DA	L	16	0.58916	0.21666	0.53333
R	F	DCR	R	16	0.51416	0.11666	0.30000
R	F	DCR	L	16	0.47333	0.24583	0.44583
L	M	S	R	16	0.79083	0.04166	0.60000
L	M	S	L	16	0.75833	0.07500	0.69583
L	M	DA	R	16	0.57083	0.13333	0.40416
L	M	DA	L	16	0.56250	0.22916	0.57916
L	M	DCR	R	16	0.47916	0.12083	0.43333
L	M	DCR	L	16	0.49583	0.19583	0.54166
L	F	S	R	16	0.79750	0.05833	0.54166
L	F	S	L	16	0.78166	0.13333	0.63333
L	F	DA	R	16	0.53916	0.07916	0.43750
L	F	DA	L	16	0.53750	0.25833	0.56250
L	F	DCR	R	16	0.43333	0.09166	0.34583
L	F	DCR	L	16	0.47750	0.17500	0.40833

HAND	SEX	TASK	EAR	N	RT FA	P(FA)	P(NO RESPONSES)
R	M	S	R	16	732.000	0.19500	0.01944
R	M	S	L	16	724.937	0.24666	0.01458
R	M	DA	R	16	955.000	0.18750	0.21597
R	M	DA	L	16	914.125	0.19083	0.20763
R	M	DCR	R	16	915.750	0.19333	0.26875
R	M	DCR	L	16	856.625	0.17500	0.29305
R	F	S	R	16	737.312	0.20500	0.01111
R	F	S	L	16	760.937	0.21250	0.00694
R	F	DA	R	16	846.875	0.17083	0.21180
R	F	DA	L	16	996.437	0.19916	0.20902
R	F	DCR	R	16	898.687	0.14916	0.32430
R	F	DCR	L	16	830.187	0.16916	0.34236
L	M	S	R	16	699.250	0.19000	0.01805
L	M	S	L	16	723.687	0.21000	0.02569
L	M	DA	R	16	843.562	0.15833	0.26388
L	M	DA	L	16	891.687	0.18666	0.22708
L	M	DCR	R	16	916.062	0.17333	0.33611
L	M	DCR	L	16	795.937	0.19666	0.30000
L	F	S	R	16	749.125	0.18750	0.01250
L	F	S	L	16	766.437	0.19666	0.02430

L	F	DA	R	16	946.687	0.16916	0.28263
L	F	DA	L	16	900.187	0.19166	0.27361
L	F	DCR	R	16	854.062	0.15916	0.38819
L	F	DCR	L	16	951.687	0.16250	0.35208

APPENDIX E

Antonym Match Task Means

ANTONYM MATCH MEANS

RT = REACTION TIME
#CORR = NUMBER OF CORRECT RESPONSES
#INCORR = NUMBER OF INCORRECT RESPONSES
S = SINGLE ANTONYM TASK
DRE = DUAL TASK WITH RIGHT EAR ATTENTION
DLE = DUAL TASK WITH LEFT EAR ATTENTION

HAND	N	RT	#CORR	#INCORR
RIGHT	96	1866.625	48.312	9.1354
LEFT	96	1801.166	49.135	9.7500

SEX	N	RT	#CORR	#INCORR
MALE	96	1986.625	46.4479	10.0312
FEMALE	96	1681.166	51.0000	8.8541

TASK	N	RT	#CORR	#INCORR
S	64	1614.375	53.953	7.2187
DRE	64	1965.500	46.046	10.5312
DLE	64	1921.812	46.171	10.5781

HAND	SEX	N	RT	#CORR	#INCORR
R	M	48	1992.229	46.5625	9.6041
R	F	48	1741.020	50.0625	8.6666
L	M	48	1981.020	46.3333	10.4583
L	F	48	1621.312	51.9375	9.0416

SEX	TASK	N	RT	#CORR	#INCORR
M	S	32	1735.187	52.0937	7.3437
M	DRE	32	2112.937	43.2500	12.0312
M	DLE	32	2111.750	44.0000	10.7187
F	S	32	1493.562	55.8125	7.0937
F	DRE	32	1818.062	48.8437	9.0312
F	DLE	32	1731.875	48.3437	10.4375

HAND	TASK	N	RT	#CORR	#INCORR
R	S	32	1671.218	53.1562	6.7187
R	DRE	32	1992.656	45.5937	10.2500
R	DLE	32	1936.000	46.1875	10.4375
L	S	32	1557.531	54.7500	7.7187
L	DRE	32	1938.343	46.5000	10.8125
L	DLE	32	1907.625	46.1562	10.7187

HAND	SEX	TASK	N	RT	#CORR	#INCORR
R	M	S	16	1762.187	52.0000	6.8125
R	M	DRE	16	2119.625	43.2500	11.4375
R	M	DLE	16	2094.875	44.4375	10.5625
R	F	S	16	1580.250	54.3125	6.6250
R	F	DRE	16	1865.687	47.9375	9.0625
R	F	DLE	16	1777.125	47.9375	10.3125
L	M	S	16	1708.187	52.1875	7.8750
L	M	DRE	16	2106.250	43.2500	12.6250
L	M	DLE	16	2128.625	43.5625	10.8750
L	F	S	16	1406.875	57.3125	7.5625
L	F	DRE	16	1770.437	49.7500	9.0000
L	F	DLE	16	1686.625	48.7500	10.5625

APPENDIX F

Continuous Recall Task Means

CONTINUOUS RECALL MEANS

RT = REACTION TIME
#CORR = NUMBER OF CORRECT RESPONSES
#INCORR = NUMBER OF INCORRECT RESPONSES
S = SINGLE CONTINUOUS RECALL TASK
DRE = DUAL TASK WITH RIGHT EAR ATTENTION
DLE = DUAL TASK WITH LEFT EAR ATTENTION

HAND	N	RT	#CORR	#INCORR
RIGHT	96	1041.989	73.3020	13.7395
LEFT	96	1058.645	76.3645	13.8645

SEX	N	RT	#CORR	#INCORR
MALE	96	1043.812	73.7812	14.5729
FEMALE	96	1056.822	75.8854	13.0312

TASK	N	RT	#CORR	#INCORR
S	64	877.031	102.015	3.7187
DRE	64	1158.515	60.218	19.0468
DLE	64	1115.406	62.265	18.6406

HAND	SEX	N	RT	#CORR	#INCORR
R	M	48	1020.645	75.0208	13.1458
R	F	48	1063.333	71.5833	14.3333
L	M	48	1066.979	72.5416	16.0000
L	F	48	1050.312	80.1875	11.7291

SEX	TASK	N	RT	#CORR	#INCORR
M	S	32	903.718	100.906	3.5937
M	DRE	32	1115.687	59.250	19.9687
M	DLE	32	1112.031	61.187	20.1562
F	S	32	850.343	103.125	3.8437
F	DRE	32	1201.343	61.187	18.1250
F	DLE	32	1118.781	63.343	17.1250

HAND	TASK	N	RT	#CORR	#INCORR
R	S	32	895.687	100.718	3.2812
R	DRE	32	1133.281	58.875	18.9062
R	DLE	32	1097.000	60.312	19.0312
L	S	32	858.375	103.312	4.1562
L	DRE	32	1183.750	61.562	19.1875
L	DLE	32	1133.812	64.218	18.2500

HAND	SEX	TASK	N	RT	#CORR	#INCORR
R	M	S	16	902.875	103.750	1.6250
R	M	DRE	16	1082.562	60.125	18.1250
R	M	DLE	16	1076.500	61.187	19.6875
R	F	S	16	888.500	97.687	4.9375
R	F	DRE	16	1184.000	57.625	19.6875
R	F	DLE	16	1117.500	59.437	18.3750
L	M	S	16	904.562	98.062	5.5625
L	M	DRE	16	1148.812	58.375	21.8125
L	M	DLE	16	1147.562	61.187	20.6250
L	F	S	16	812.187	108.562	2.7500
L	F	DRE	16	1218.687	64.750	16.5625
L	F	DLE	16	1120.062	67.250	15.8750