AN INVESTIGATION OF AGE DIFFERENCES IN DIVIDED ATTENTION AND INTRAHEMISPHERIC COMPETITION

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ABSTRACT

Following several pilot experiments on intrahemispheric competition a primary experiment was conducted to investigate adult age differences in divided attention and intrahemispheric competition. Right handed subjects performed a repetitive finger tapping task, with the right or left index finger, either alone or with a concurrent verbal task (Tongue Twisters, Verbal Fluency, or Sentence Repetition). All subjects were exposed to each of the three concurrent tasks with one right and one left hand trial within each concurrent task condition, and task and hand orders were counterbalanced. The subjects were instructed to divide their attention equally between the two tasks in concurrent task conditions. There were four control trials of single task tapping with each hand, and these trials were evenly spaced throughout the experiment from beginning to end. All trials were of 20 seconds duration with 30 second inter-trial intervals.

Subjects tapped faster with the right than the left hand and young subjects tapped faster than older subjects. Tapping performance improved with practice, and improvement was similar for both hands and for each age group.

All three verbal tasks interfered with concurrent finger tapping performance. The Tongue Twister task was associated with the greatest degree of interference while Verbal Fluency and Sentence Repetition were substantially less disrupting. Age differences in overall degree of interference were found for the Verbal Fluency and Sentence Repetition tasks.

Patterns of intrahemispheric competition (greater right than left decline from baseline tapping) were found for each task, with Sentence Repetition providing the most powerful and consistent effects. There was a tendency for the Tongue Twister task to result in bilateral yet somewhat asymmetric tapping decrement. The post hoc establishment of a laterality criterion based on single task tapping performance resulted in more powerful findings of intrahemispheric competition, particularly for the Verbal Fluency condition. Age differences in intrahemispheric competition were not found for any of the concurrent task conditions.

The results were discussed in terms of information processing and Kinsbourne's functional cerebral distance model. It was concluded that the elderly may require a greater portion of processing capacity to be allocated for the organization of the division of attention, and that intrahemispheric competition may be a stable phenomenon which does not represent a particular problem area in the elderly.

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INTRODUCTION

In the chapter on memory in the *Handbook of the Psychology of Aging* (Birren & Schaie, 1977), Craik lists six main areas that he believes should be pursued as focal issues for future research in gerontological psychology. One of these areas is "the nature of the age decrement in divided attention situations" (p. 415).

This dissertation is concerned with age differences in divided attention, particularly with regard to simultaneous dual task performance of distinctly different tasks. Special attention is given to the role that "intrahemispheric competition" might play in age differences in divided attention. Pilot experiments are summarized and one primary experiment is described which considers the questions of whether there are significant age differences in divided attention and whether the pattern of intrahemispheric competition, if apparent, is different for older adults than for young adults.

In chapter one a review of the literature is presented. The first section reviews the studies on divided attention. Historical background and conceptual aspects are covered along with experimental studies and a discussion of problems with research on the topic. The second part of chapter one deals with research on adult age differences in divided attention. The third part of the chapter involves the concept of intrahemispheric competition, which stems from the "functional cerebral distance model." The research evidence is presented and the relevance to the study of divided attention is examined. The chapter concludes with a statement of the problem.

Chapters two, three and four describe the research which forms the basis for the present dissertation. The pilot research is briefly discussed in chapter two. The primary purposes of the pilot research were to replicate previous findings on intrahemispheric competition and to explore the effects for a variety of concurrent tasks. The primary experiment is described in chapter three. Three specific hypotheses are advanced and the primary experiment attempts to provide direct evidence relevant to each hypothesis. Chapter four discusses results that are not central to the three hypotheses and also presents serendipitous findings that are relevant to the hypotheses. The final chapter presents a discussion of the results of the primary experiment.

CHAPTER 1

REVIEW OF THE LITERATURE

Divided Attention

Historical Background

Spelke, Hirst and Neisser (1976) provide an overview of the historical background for research in divided attention. They point out that most early psychologists (e.g., James, 1890; Woodworth, 1921) believed that consciousness could only be directed to a single activity at a time. Conscious attention to two different actions performed at the same time was thought to be possible only if they were coordinated into a single, higher order activity, or attended to in rapid alternation. Otherwise, it was assumed that at least one of the activities was being carried out "automatically," i.e., without conscious control.

The biologist Loeb (cited in Welch, 1898) proposed that two signals that occupy the same limited capacity system might be expected to interfere with one another. This idea was put to test by his student, Jeanette Welch, in the first issue of the *American Journal of Physiology* (Welch, 1898). Maximal hand grip was combined with other tasks such as reading and calculation, and interference between tasks resulted. Welch introduced the idea of a coefficient of attention. The idea was that if one used a standard secondary task (e.g., maximal hand grip), it would be possible to use the degree of interference with the standard task as a measure of attention demands of the primary task (e.g., reading or calculation). As pointed out by Posner (1978), this idea of examining the attention to one task by its effect on other tasks has been used subsequently in many psychological literatures.

Early studies of divided attention were introspectionist. Paulhan (1887) recited one poem while writing another or while executing mathematical calculations, and reported that attention alternated between the two activities. Solomons and Stein (1896) reported that when reading stories while writing at dictation, one activity was performed unconsciously. Utilizing the same tasks, Downey and Anderson (1915) claimed that a genuine division of attention was accomplished.

Modern studies of attention have avoided the dependence on introspection which characterized the early work, and have usually employed simultaneous perceptual cognitive rather than simultaneous motor tasks. That is, according to Spelke et al. (1976), division of attention generally has not been defined by simultaneous directed activity, but by concurrent processing in two distinct "channels." In the latter case, the information to be processed may differ between channels but the tasks are really the same. Spelke et al. comment that only a few studies have required subjects to perform two distinct simultaneous tasks, and that none of these studies examined changes in dual-task performance with practice. In any case the studies on divided attention, however defined, will be reviewed in later sections. Attention first will be turned to the concept of divided attention.

The Concept of Divided Attention

If one explores the literature on divided attention it will become apparent that there is not a clear, unified concept of divided attention among researchers in the area. As alluded to above, there seems to be a real lack of synthesis of research relevant to the study of divided attention, as many research studies emanate from diverse orientations. Different researchers may use the term "divided attention" to describe very different experimental situations, and some authors use different terms when they are really studying the same thing but do not acknowledge relevant research from other subdisciplines.

It is not difficult to illustrate the diverse ways of conceptualizing divided attention. There are experiments which examine dual task performance where two distinct tasks are performed simultaneously (e.g., Allport, Antonis, & Reynolds, 1972). Some studies employ tasks that, although not the same, are somewhat similar (e.g., Tune, 1964). Divided attention is also explored via tasks that are basically the same, such as experiments which assess performance on simultaneous signal detection tasks (e.g., Long, 1975). In this kind of research the input modalities vary but the tasks are really the same —to detect a certain stimulus. Research on divided attention need not be restricted to the dual task environment. Indeed, Craik (1977) talks of dividing attention between specific aspects of performance on a single task such as between input and holding or between holding and responding. Finally, there is a body of research on divided attention which is not even discussed in terms of divided attention. This is the research on intrahemispheric competition, which is entirely relevant to studies of simultaneous dual task performance of two distinct tasks. The intrahemispheric competition literature will be discussed separately in a later section.

According to Posner (1978), the most fundamental issue with regard to the study of divided attention is "whether the experimenter measures those aspects of the primary and secondary task that are likely to require the central processor" (p. 154). This is consistent with the view of Welford (1968), who in his review of dual task research up to that time concludes that "the effects seemed clearly to be the result of an overloading of some central mechanism" (p. 132). As long as tasks involve the central processor it does not seem to matter what kinds of tasks are used. The secondary task can be either continuous (e.g., in pursuit tracking) or discrete (e.g., as in a reaction time task), or it might require an overt response or merely a detection and later report. In this vein Ostry, Moray and Marks (1976) found that their results were similar regardless of the type of stimuli used (symbolic or semantic). Posner found that his results were similar even for non-simultaneous tasks in which task orders and inter-task intervals were varied. Posner concludes not only that there is evidence for interference in experiments on dual task performance, but also that there are "clear indications that dual task techniques of nearly every variety work in much the same way" (p. 154).

What the aforementioned suggests is that it may not really matter whether the tasks are distinct or similar, or even whether they occur entirely simultaneously. Therefore I will lump the diverse research together under the loose rubrics of divided attention and dual task performance (in itself a subset of divided attention).

Finally, some comment is warranted about the concepts of "primary" and "secondary" tasks. What is meant by primary and secondary task seems to be no more clear than the concept of divided attention itself. It appears that there are at least three ways to utilize primary and secondary tasks. One view is that the primary task is the only task of real interest per se, and no measurements are made in regard to secondary task performance. The concern is simply with whether the secondary task affects performance on the task of interest, i.e., the primary task. A second approach is to give subjects explicit instructions as to which task to attend to more, and the task for which subjects are told to attend to more is the primary task. Performance on the secondary task may or may not be of interest. Finally, one can view the tasks in terms of the subject's phenomenal experience. That is, the primary task is regarded as the task that was actually attended to more, regardless of any instructions. This means that a primary task as defined by the experimenter's interest or instructions could be viewed as a secondary task if the subject in fact attended to it less. The concepts of primary and secondary task thus are ambiguous although they must be referred to in this review.

Models of Attention and Time Sharing

If models of information processing are classified according to their mechanisms for resource or attention allocation, they may be broken down into two basic types: pooled capacity models or stage models (Whitaker, 1979). The pooled capacity class of models (e.g., Kahneman, 1973; Moray, 1967; Norman & Bobrow, 1975) describes attention as essentially a unitary resource. Tasks which require attention will show decrements in performance when the task demands exceed the available capacity of this resource. In contrast to pooled capacity models, stage models (e.g., Kantowitz & Knight, 1976; Sternberg, 1969) present attention as a resource which is available independently for each of several processing requirements: "When task demands overload the system, they do so at one or several specific stages. Decrements in performance will be sensitive indicators of which stages are affected by which requirements" (Whitaker, 1979, p. 72). Although numerous studies are supportive of one kind of model or the other, the research as a whole does not yet offer unequivocal support for either class of models.

Broadbent (1958, 1971) is primarily credited with the "limited capacity channel model" which asserts that "the brain, in its moment-to-moment decision taking regarding both immediate and potential future response, acts as a single communication channel of limited capacity" (Allport, Antonis, & Reynolds, 1972, p. 225). According to this view, performance of two or more concurrent tasks can only be maintained by the rapid alternation of attention. This is consonant with the views of early psychologists mentioned previously.

Stage models (e.g., Sternberg, 1969) normally assume that each stage has its own independent source of capacity rather than drawing upon some common source, as postulated by capacity models. Predictions of stage models vary according to assumptions made about serial versus parallel processes, the level at which capacity is allocated, etc. (Townsend, 1974).

Finally, Kantowitz and Knight (1976) have formulated a "hybrid" model. They propose that a limited capacity channel model accounts for one pattern of results while a stage model accounts for a different pattern, and that a combination of both types of models is necessary to explain the research findings. Kantowitz and Knight stress the importance of including at least two levels of difficulty for both tasks and assessing performance on both, especially if one wishes to test the validity of one time sharing model vis-à-vis another.

Research with Similar Simultaneous Tasks

Studies which employ similar tasks are generally of two types. One type involves signal detection and the other type short term memory. Dichotic listening studies fall under the latter type but will be discussed in the section on age differences in divided attetion. Except for the experiments of Mowbray, all of the subsequent studies fall under the framework of signal detection.

Early research by Mowbray (1952, 1953, 1954) required subjects to report on data such as letters, digits, or prose passages which were presented either visually or aurally. In support of a limited capacity model, it was concluded that subjects could not deal adequately with two different streams of information, one presented to the eyes and one to the ears, at the same time.

In an experiment by Bahrick and Shelly (1958), the primary task was to press the appropriate one of four keys under the right hand in response to four lights which appeared one at a time at 580 msec intervals. The secondary task was to press the appropriate one of four keys under the left hand in response to random digits from 1 to 5 presented aurally. A performance decrement was found on the primary task when the secondary task was added. There were four levels of difficulty. Secondary task performance remained stable under all levels of primary task difficulty. What the authors designated as the secondary task actually may have been the higher order task. In any case these results are consistent with a limited capacity model, as are the other studies mentioned in this section.

For Tulving and Lindsay (1967) the primary task was a visual judgment task in which subjects had to detect circular patches of white light on a dark background and estimate their intensity. The secondary task involved auditory judgment (pure tones). Judgments were made according to a 1 to 8 scale of perceived intensity for both tasks. Decrements were found on both tasks under dual versus single task conditions (consonant with both the limited capacity and variable allocation models).

A considerable amount of the research on divided attention has been carried out within the framework of two-channel auditory signal detection (e.g., Gilliom & Sorkin, 1974; Ostry, Moray, & Marks, 1975; Sorkin, Pastore, & Pohlmann, 1972; Sorkin, Pohlmann, & Gilliom, 1973). The concern in these studies is "whether, and to what extent, human observers can monitor simultaneously occurring independent events in two separate sensory input channels" (Puleo & Pastore, 1978, p. 153). In the experiment of Puleo and Pastore (1978) there were three conditions of interest: a single channel condition, a selective attention condition, and a divided attention condition. The single channel condition involved monaural stimulation while the latter two conditions consisted of dichotic presentation. In the selective attention condition subjects were required to ignore one channel and make a discrimination response only for the other channel. In the divided attention condition subjects made separate discrimination responses to the targets in each channel. The authors found that (a) when the signals in each earphone were within the same critical band (the assumed single processing unit in frequency domain), there was a decrement in detection performance in both the selective and divided attention conditions compared with the monaural condition; and (b) when signals were separated in frequency by several critical bands, a decrement occurred only in the divided attention condition. Puleo and Pastore concluded that the deficits are related to the requirements for time sharing.

Long, a student of Broadbent at Cambridge University, has published several experiments from his dissertation on divided attention. His work is also within the signal detection paradigm and emanates from studies such as Moray and O'Brien (1967) in regard to verbal signals, and Egeth and Pachella (1969) in regard to nonverbal signals. In Long's experiments of interest (Long, 1975, 1976a, 1976b, 1976c, 1977) nonverbal signals are presented simultaneously, usually consisting of auditory frequency and light intensity. The relevant experiments, in which findings are consistent with a limited capacity model, are summarized below.

In each of Long's experiments, he has found that when signals were presented together each signal was recognized less well than when presented alone. Long (1975) concluded that this effect requires some assumption of limited processing capacity and is not due simply to confusability between the signals or to artifacts occurring after signal identification.

In follow-up experiments Long (1976a) concluded that the limitation of processing capacity exemplifies itself in "shared" rather than "all-or-none" processing on a trial. This is consistent with earlier findings of Tulving and Lindsay (1967) and of Lindsay, Taylor and Forbes (1968), and contradicts the notion that one must alternate between activities in divided attention situations.

In regard to the controversy between limited capacity (interactive) and stage (additivity) models, Long (1976b) concluded that the efficiency of performance on two simultaneously presented signals is interactive rather than independent. His results are thus supportive of a limited capacity model and are consistent with findings of other researchers such as Lindsay and Norman (1969) and Massaro and Kahn (1973).

Long (1976c) tested the assumption of Broadbent (1971) that the divided attention effect is the exclusive or at least the primary effect which results when subjects attempt to recognize signals presented together. Long sought to ascertain whether there is an "order of report effect" (i.e., poorer performance for signals reported second). In Experiment 1 the results showed: (a) an overall impairment of performance with simultaneous signals; (b) a contribution both of divided attention and order of report effects to the decrement, with a suggestion of the primary of the order of report effect; and (c) a significant interaction between the order of report effect and modality, such that visual signals showed the greater effect. In Experiment 2 the assumption was only partially confirmed, as a significant decrement in performance occurred only for the second of two successively presented signals.

Long (1977) found that presenting signals successively reduces impairment while presenting easy signals successively eliminates impairment. He concluded that the processing of multiple signals is characterized by (a) a loss associated both with the acquisition of the storage of information, and (b) preferential processing of visual signals over auditory ones.

The aforementioned studies clearly suggest decrements in dual versus single task performance. One might ask when a secondary task can be expected to *not* interfere with performance of the other task. The answer, according to Greenwald (1972), is that noninterference of the secondary task is possible "only if the two tasks do not share in the use of any limited-capacity information-processing systems" (p. 52). Such a situation occurs when neither of two simultaneous tasks requires a decision based on stimulus information (Adams, 1966, p. 190). If time sharing of decisions is required, the limited capacity decision process can be circumvented under a condition of "ideomotor compatibility."

Ideomotor (IM) compatibility refers to "the dimension denoting the extent to which a stimulus corresponds to sensory feedback from its required response" (Greenwald, 1972, p. 52). Ideomotor theory (Greenwald, 1970; James, 1890) proposes that responses are centrally coded by representations of their sensory feedback. The response code is directly activated by signals that closely resemble sensory feedback from the response (such as saying a word in response to hearing it said). "A relationship between stimulus and response of ideomotor compatibility is defined, then, as one in which the stimulus resembles sensory feedback from the response" (Greenwald & Shulman, 1973, p. 70). The concept of IM compatibility overlaps with, but is not identical to, stimulus-response (S-R) compatibility which involves highly learned associations.

Greenwald (1972) tested the assumption that perfectly efficient time sharing of two simultaneous decision tasks would occur under a high IM compatibility condition. Inefficient time sharing was expected under a low IM compatibility condition. In the experiment, two simultaneous stimuli were presented, one visually and the other auditorily. The visual stimulus was an arrow pointing either left or right (presented on a television monitor). The auditory stimulus was the word "left" or "right" (heard through headphones). Two responses were required on each trial: moving a switch left or right (using the preferred hand) in response to one stimulus, and saying the word left or right in response to the other stimulus. The *high IM compatibility* *condition* involved the same stimuli and responses: moving the switch left or right according to the arrow direction and saying the word left or right in response to the auditory word stimuli. Greenwald reasoned that these combinations bypass the limited capacity response selection mechanism and therefore would not result in interference. The *low IM compatibility condition* involved moving the switch left or right in response to the words left or right (respectively) and saying left or right depending on the arrow direction. Although these combinations are considered to be S-R compatible in that highly overlearned associations are involved, correct response selection for these combinations requires the subject to activate response representations not directly activated by the stimuli. Greenwald reasoned that there would be interference in this condition since the tasks must compete for access to the hypothesized limited capacity response selection mechanism.

The results were clearly supportive of Greenwald's predictions. Greenwald concluded his article by raising the question of whether efficient time sharing could be produced if only one of the two tasks were highly ideomotor compatible. There is experimental research which supports this notion (Allport, Antonis, & Reynolds, 1972) but a study by Spelke, Hirst and Neisser (1976) contradicts the IM hypothesis since efficient time sharing occurred when neither task was high in IM compatibility (however, subjects had considerable practice on these tasks). These studies will be discussed in the following section as they fall under the rubric of distinct simultaneous tasks.

Research with Distinct Simultaneous Tasks

According to Kantowitz and Knight (1976) the "basic time sharing paradigm" requires concurrent performance of two distinct tasks. Such studies do not simply vary input modalities or the information presented to the other channel. The second task involves actually performing a different activity, such as remembering digits while driving a car in heavy traffic (Brown, 1962, 1965a) or carrying out various card sorting tasks while processing a list of words for immediate recall (Murdock, 1965). The research literature on intrahemispheric competition is entirely relevant to the divided attention studies of dual task performance of simultaneous and distinct tasks. However, that line of research will be discussed separately since the experiments have been carried out in a different subdiscipline within psychology and have not been integrated with other paradigms relevant to the study of divided attention.

Welford (1968) reviewed the studies that had been done on dual task performance (most of them involving distinct tasks) prior to 1968. These experiments (Bahrick, Noble, & Fitts, 1954; Bornemann, 1942; Broadbent, 1956; Brown, 1962, 1965a, 1965b; Brown & Poulton, 1961; Garvey & Taylor, 1959; Kalsbeek, 1964, 1965; Murdock, 1965; Noble, Trumbo, & Fowler, 1967; Poulton, 1958b; Schouten, Kalsbeek, & Leopold, 1962; Trumbo, Noble, & Swink, 1967; Tune, 1964) will not be discussed here as they are adequately summarized by Welford (pp. 131-133). After having reviewed the above research, Welford concluded that "these studies indicate clearly that increase in the load of either the primary or the secondary task beyond a critical point can greatly impair performance at one or both, and that adding a secondary task can show up differences in the loads imposed by different primary tasks which are unobservable when they are performed alone" (p. 133).

Whereas Welford's conclusion is consistent with a notion of limited capacity, some of the more recent studies have not been as clearly supportive of the pooled capacity models. Kantowitz and Knight (1974, 1976) formulated their hybrid model on the basis of experimental findings that, as a whole, did not entirely support either a limited capacity or a stage model. Research by Whitaker (1979) is also concurrent with the view that neither pooled capacity nor simple stage models are clearly supported.

The problems with research in divided attention will be discussed in the next section, but before proceeding, it is instructive to consider the upper limits of human dual task performance rather than only focussing on decrements. That is, to what extent can people be trained to perform complex tasks simultaneously with little loss in efficiency?

Allport, Antonis and Reynolds (1972) have shown that people can attend to and repeat back continuous speech (verbal shadowing) at the same time as taking in complex, unrelated visual scenes, or even while sight reading piano music. The authors found that divided attention was very good in both types of pairing, and in the case of sight reading was as good as with undivided attention. The accuracy of speech shadowing was virtually unaffected by either of the dual tasks. Allport et al. concluded that a "multi-channel" hypothesis involving parallel, independent processors is more appropriate than a generalized single channel hypothesis. Even so, Greenwald's (1972) ideomotor hypothesis (developed within a framework of a limited channel capacity model) is consistent with the findings of Allport et al., as the verbal shadowing task is highly ideomotor compatible.

Shaffer (1975) extended the results of Allport et al. by showing that messages can be of the same linguistic type. That is, both messages can be verbal. The combinations do not have to be verbal and nonverbal in order to attain efficient dual task performance. Shaffer demonstrated that a skilled typist could type successfully at high speed from a visual text while simultaneously performing another verbal task, such as shadowing prose or reciting nursery rhymes. However, the typist had great difficulty in combining auditory typing with the secondary tasks.

It should not be surprising that people can improve their performance in dual task situations with practice. Ostry, Moray and Marks (1976) reported marked practice effects on the detectability of targets. Kinsbourne and Hicks (1978) reported a study by Kinsbourne, La Casse and Hicks (unpublished) in which accomplished musicians, after much practice, learned to play simultaneously two different tunes on a piano, one with each hand. The aforementioned experiments by Allport et al. and by

Shaffer, and research by Underwood (1974) are suggestive of practice effects as well. However, very little research has acknowledged this point explicitly.

The major source of evidence on improvement with practice in dual task situations comes from the study by Spelke, Hirst and Neisser (1976). Spelke et al. carried out a contemporary study that is in the tradition of the early introspectionists (e.g., Paulhan, 1887). They deliberately included a systematic and extended practice regimen for their two subjects. What separates the Spelke et al. study from most of divided attention research is that the authors were truly interested in tapping high levels, through practice, of complex dual task performance. Such an approach meshes well with the views of many humanistic psychologists (e.g., Maslow, 1970) who believe that human functioning can be best understood by focussing on the upper limits of functioning, regardless of whether the domain of concern is physical, intellectual or personality.

Spelke et al. had their subjects practice reading short stories while writing lists of words at dictation. After weeks of practice the subjects were able to copy words, detect relations among words, and categorize words for meaning, while reading short stories as effectively and as rapidly as they could read them alone. The authors concluded that such performance is not consistent with the notion that there are fixed limits to attentional capacity, and commented as follows:

> Since we did not dictate connected discourse to our subjects, we do not know whether they would have become able to read normally while following another meaningful sequence over time. That achievement remains to be demonstrated. It seems clear, however, that they understood both the text they were reading and the words they were copying. In at least this limited sense, they achieved a true division of attention: they were able to extract meaning simultaneously from what they read and from what they heard. . . . Although individual strategies may have their own limitations, there are not obvious, general limits to attentional skills. Studies of attention which use unpracticed subjects, and infer mechanisms and limitations from their performance, will inevitably underestimate human capacities. Indeed, people's ability to develop skills in specialized situations is so great that it may never be possible to define general limits on cognitive capacity. (1976, p. 229)

Problems with Research in Divided Attention

According to Duncan (1979), the idea that single tasks and single task processes compete for common resources has dominated the study of divided attention. Duncan's thesis is that this idea captures only part of the problem of dual task performance. He points out that "performance decrements may often result from failure (or limits) of new or 'emergent' processes whose existence depends on the particular 'set' of tasks combined" (p. 216). What Duncan is saying is that the dual task situation is not the same as adding two single tasks together (i.e., the whole is somewhat different from the sum of its parts). When a secondary task is added, unique "emergent processes" now exist which were not relevant to the single task environment. Duncan convincingly explains that emergent processes have been demonstrated in regard to visual identification, response choice, and motor programming, and in some of the most widely studied experimental situations such as visual search and PRP (psychological refractory period). The details of these emergent processes need not concern us here. The point is to realize that they exist, and that interpretations of dual task experiments should take this into account. Thus Duncan calls for a new perspective: a realization that "in any divided attention experiment, performance may reflect an interaction between resource limitation, single task processes, and emergent aspects of the whole situation" (p. 227).

If one is interested in estimating and comparing the loads imposed by certain tasks by observing their effects on another task, then the three areas of concern elaborated by Welford (1968) should be considered. The first concern involves the problem of whether attention can be truly divided between two tasks or whether it alternates rapidly between one and the other. More specifically, "there is some question whether the primary task occupies the single-channel continuously but not completely at any one instant, or whether occupation is complete but intermittent so that spare capacity is in the form of 'gaps' during which the single-channel is free" (p. 134). According to Welford, this is a difficult question which remains to be answered.

Welford's second concern is the stability of capacity. Most dual task studies have tacitly assumed that the subject's basic capacity remains the same regardless of whether a secondary task is added, and regardless of the severity of demands of the secondary task. However, Welford reports that some research findings on the effects of pacing raise the question of whether some genuine increase of capacity occurs under pressure for speed. In fact, Kalsbeek and Ettema (1964) distinguish between the capacity a subject is willing to spend and the maximum he can use in an emergency. In any case one must recognize that the assumption of stability of capacity is a moot issue.

A third area of concern for Welford involves the coordination of primary and secondary tasks. Kalsbeek (1964) noted that the subjects in his dual task experiments tended to build up a rhythmic pattern of performance in which the two tasks were regularly interdigitated. When this was achieved the dual task impairment was reduced, implying that the tasks were no longer separate but had been combined into one complex task. Further evidence for improved dual task performance resulting from task coordination comes from studies on tracking (Adams & Chambers, 1962) and on serial reaction times (Dimond, 1966). Task coordination seems to be facilitated when the signals in one or both tasks come at regular intervals or are otherwise predictable. Although task coordination may be fostered by training (Kalsbeek & Sykes, 1967), the likelihood of effective coordination is greatest when the total loading is moderate, and coordination may break down when the total loading is severe. Welford (1968) comments that "such co-ordination obviously complicates measurement of the load imposed by the primary task in terms of the impairment of performance at the secondary, although it remains possible to make such measurement in principle" (p. 136).

In regard to signal detection studies, Long (1976c) has demonstrated that it is important to control for an order-of-report effect. That is, performance may be poorer for signals reported second.

A general problem with divided attention research, as pointed out by Spelke, Hirst and Neisser (1976), is that researchers follow a decrement approach while ignoring exploration of the upper limits of human capacity for dual task performance. Such an approach can only underestimate human capacity.

As mentioned earlier, an unfortunate shortcoming of research on divided attention is the lack of synthesis among different studies from different subdisciplines which utilize different terminologies and approaches to study the same kind of problem. I am not calling for a uniform approach to the study of divided attention, but simply for increased awareness of what other researchers in different areas have contributed. In the following pages I will endeavor to integrate the divided attention research with the literature on aging, and apply a neuropsychological model to the problem of age differences in divided attention.

Age Differences in Divided Attention

According to Craik (1977), "one of the clearest results in the experimental psychology of aging is the finding that older subjects are more penalized when they must divide their attention, either between two input sources, input and holding, or holding and responding" (p. 391). Craik's terminology in regard to divided attention is quite different than the terminology of other researchers who talk of "dual-task performance" (e.g., Kantowitz & Knight, 1976). Craik is not talking about dual task performance of distinctly different tasks. Division of attention "between two input sources" refers to the kinds of studies discussed under the section on similar simultaneous tasks, and includes research on dichotic listening. Division of attention "between input and holding" and "between holding and responding" can be regarded as intra-task division of attention (i.e., the division of attention occurs within one particular task rather than between two distinct tasks or between different input sources). Although Craik does not refer to divided attention in the same sense as, for example, Kantowitz and Knight, there are some studies in the literature on aging which do involve dual task performance. Age differences in divided attention will be discussed both in Craik's terms and in terms of dual task performance.

Perhaps one can regard the diverse conceptualizations of divided attention as different kinds of divided attention, or simply as different avenues from which divided attention is explored. However, it is not clear whether general conclusions about divided attention can be made without specifying that they may apply only to the specific manner in which the concept is operationalized. In regard to age differences, one must be cautious about interpreting findings as genuine age-related changes since age differences may be found for a variety of other reasons (see Schaie, 1977, for a detailed exposition of methodological issues in gerontology). With these limitations in mind let us proceed to examine the case for age-related changes in situations which require divided attention, however defined.

Division of Attention Between Two Input Sources

Broadbent and Gregory (1965) presented information simultaneously to two different input modalities. Subjects had to remember three visual items (digit-letter-digit) and three auditory items (letter-digit-letter). Older subjects performed more poorly than young subjects in this experiment.

In a study by McGhie, Chapman and Lawson (1965), which also used a bisensory paradigm, five numbers were presented visually while at the same time five other numbers were presented auditorily at a 2-second rate. One number was repeated, and the task was to detect and write down the repeated number. No age differences were found when the repeated number occurred first on the auditory channel. However, substantial age decrements were found when the repeated number first occurred visually.

Most of the age-related studies involving two input sources have been experiments on dichotic listening. In these experiments two short series of digits, letters or words are presented simultaneously, one series to each ear. The subject typically recalls items from one ear before recalling the series of items from the other ear, provided the rate of presentation is at least one pair per second. Subjects normally attend to one ear more than the other. As a result, more items are usually recalled from the series of items presented to the attended "channel." This series of items is referred to as the first "half-set" of items. The series of items presented to the unattended (or at least lesser attended) channel is referred to as the second half-set. In general, more words are recalled from the first half-set.

Inglis and Caird (1963) compared a wide age range of subjects on dichotic listening performance for recall of digits. They found that there were no age differences in ability to recall the first half-set of digits. However, progressive age-related decrements were found in regard to reproducing the second half-set of digits. The authors interpreted their findings in terms of an age-related short term storage deficit, citing Broadbent's (1958) claim that the first half-set of digits does not involve storage while the second half-set must pass through the storage process. In any case, this classic study stimulated a considerable amount of research on age differences in dichotic listening.

Craik (1977) has reviewed the literature on dichotic listening in regard to aging (Caird, 1966; Caird & Inglis, 1961; Clark & Knowles, 1973; Craik, 1965; Inglis, 1964; Inglis & Ankus, 1965; Inglis & Sanderson, 1961; Inglis & Tansey, 1967; MacKay & Inglis, 1963; Schonfield, Trueman, & Kline, 1972; Weiss, 1963). The findings of Inglis and Caird (1963) generally have been confirmed, except that later studies tend to show age decrements for both half-sets. According to Craik (1977), this is probably the result of a procedural difference between experiments. The earlier studies did not specify the order of recall—that is, subjects could choose which ear to attend to and from which ear to recall first. In later experiments, however, channel 1 was specified, either before or after presentation. Since older subjects show a greater discrepancy between right and left ear performance than do younger subjects, and are particularly bad at recalling items presented to the left ear (Clark & Knowles, 1973), older persons may tend to concentrate on their better (right) ear when ear order is unspecified. Consequently the better channel is attended to and recalled first, which results in good performance for the first half-set but very poor performance for the second half-set. When the order is specified, the preferred ear is channel 1 on only half the trials, thereby resulting in some age-related decrement for both half-sets.

Craik (1977) concludes that "there is no doubt that the dichotic listening paradigm provides a sensitive index of age-related decrements, but it is not clear which processes are involved" (p. 390). Craik rejects the suggestion of Inglis and Caird (1963) that the second half-set is held in a pre-perceptual auditory store and that material in this store is lost more rapidly with age. He also dismisses the hypothesis that the findings can be explained by older people being more vulnerable to interference. Craik proposes that the findings are best interpreted in terms of "depth of processing" (Craik & Lockhart, 1972).

According to Craik and Lockhart, the durability of a memory trace depends on how deeply the stimulus is processed (i.e., the amount of attention allocated to the stimulus). "Depth" refers to the number and qualitative nature of perceptual analyses carried out on the input. In this vein it has been suggested (Treisman, 1964) that division of attention is associated with shallower levels of analysis of the unattended stimulus, which results in more rapid loss of information. Craik (1977) reasons as follows:

> There is much evidence that older subjects are especially penalized in situations where they must divide their attention; perhaps their capacity is largely taken up in 'programming' the division of attention leaving relatively little capacity to process the stimuli (Craik, 1973). If older subjects' processing capacity is differentially reduced in this way, they would process one or both of the dichotic channels less deeply, and this, in turn, would lead to poorer retention. (p. 391)

Division of Attention Between Input and Holding

The studies reviewed by Craik (1977) do not seem to fall specifically under this type of divided attention situation. Perhaps the recent research of de Bosch Kemper (1979) is illustrative of this variety of division of attention. In his experiments on age differences in "continuous recognition learning," de Bosch Kemper had his subjects progress through an extensive series of cards, each consisting of two, three-digit numbers. The task was to remember which items had been presented so that on later test trials, a subject could indicate which item was new or old. The lag between the appearance of an item and its reappearance on a test trial could be zero (i.e., the test trial immediately follows the card on which the old item appeared), or the lag could be several trials (i.e., three or four card presentations between an item's first appearance and its reappearance on a test trial). Such a task requires a division of attention between input and holding. One must learn new items while simultaneously holding onto items already learned, since any of the items may reappear on a subsequent recognition test trial. As expected, older subjects had more difficulty with the task but there were complex results involving differential effects of informative feedback.

Division of Attention Between Holding and Responding

In a study by Kay (1953), replicated by Kirchner (1958), subjects had to remember one of 12 light positions, each corresponding to a morse key below each bulb. When the task was to press the key when its corresponding light appeared (which extinguished the light and caused another one to come on), older subjects performed as well as younger subjects. However, when the task was complicated by asking subjects to press the key corresponding to the *previous* light, the older subjects did not perform as well as the younger ones. The age decrement was even more severe when the memory load was increased by requiring subjects to work "two back" or "three back" in pressing keys corresponding to previous lights. "Apparently the division of attention between memory and response was especially disruptive to the performance of older subjects" (Craik, 1977, p. 391).

In a study by Talland (1965), subjects had to hold one selected item in memory while reporting others. More specifically, the task involved recalling a series of words in which only one of the words in the list was unrepeated. When the instruction was to report the entire list of words while leaving the unrepeated word last (requiring holding in the midst of responding), performance steadily deteriorated with age. Talland interpreted his findings in terms of Broadbent's (1958) limited capacity model of perception and immediate memory.

Dual Task Performance

It should be mentioned that differentiating studies of dual-task performance from the other studies of division of attention (that is, between two input sources, input and holding, and holding and responding) is somewhat artificial and arbitrary. For example, dichotic listening could be regarded as a single task or it could be viewed as a dual task situation in which each task is the same except for the source of input. The studies described in the sections on dividion of attention between input and holding and between holding and responding could be viewed in terms of two tasks as well. Although the empirical research has been broken down into separate sections, it should be realized that this has been done to correspond with varying approaches and terminologies and does not imply that the studies in different sections are necessarily tapping different processes. This also holds true for the distinction between similar and distinct tasks. Experiments are discussed in terms of dual task performance simply if the researchers conceive of their studies as employing two different tasks.

Craik (1977) reports that Talland (1962) showed that older subjects were particularly poor at performing two tasks simultaneously. He also mentions a study by Broadbent and Heron (1962) in which a visual letter cancellation task was paired with a task requiring subjects to monitor a series of auditory letters for a repeated letter. While young subjects performed moderately well with both tasks, older subjects tended to concentrate on one task while performance on the other deteriorated markedly.

Craik (1977) indicates that "the results of these and similar experiments led Welford (1958, 1962, 1964) to formulate the influential notion that one major source of performance decrements in the elderly is the disruption of short term memory by shifts of attention between perception and recall" (p. 391). The expression "shifts of attention" is noteworthy since a shift would imply an "all-or-none" model in which attention alternates between tasks. This is different from the concept of a true division of attention where one would presume that some attention is simultaneously allocated to each task. As mentioned earlier, there is no consensus on which is the case. The point is brought out to clarify that some researchers talk about "division of attention" even though they might disagree with the concept implied by a true division, as opposed to shifting or alternation of attention.

Craik (1973) reported two experiments in which an auditory signal detection task was paired with a short term recognition memory task. The memory task consisted of a serial string of letters or digits followed immediately by a probe letter or digit, and the subject was asked to judge whether the probe had been in the preceding string. In the first experiment older subjects performed more poorly than younger subjects on both tasks, even though all subjects could perform each task adequately alone. The second experiment was similar except the tasks were made more difficult by requiring "relatively deep, semantic processing" (Craik, 1973, p. 3). Age decrements were more severe, and there was also poorer performance of older subjects on the memory task alone. Craik concluded from these studies that older subjects have special problems in situations where attention must be divided between two sources of information.

In sum, the literature on aging is consistent with the notion that older persons have problems, relative to their younger counterparts, in situations demanding divided attention. However, the decrements may not be uniform across modalities. Craik (1977) cites several studies which suggest that divided attention is considerably less problematic when a memory task involves the auditory modality (Anderson & Craik, 1974; Broadbent & Gregory, 1965; Craik, 1973; McGhie, Chapman, & Lawson, 1965). Craik (1977) suggested that "auditory inputs can be held briefly whether they are attended to or not. Older subjects can also make use of this 'cost-free' encoding. When the input is visual, however, attention is required; older subjects have less processing capacity to spare in the divided attention situation, thus their performance on visual memory tasks is especially poor" (p. 392).

Intrahemispheric Competition

Most of the research on divided attention has emphasized the results of simultaneous task pairings and the implications for the various models of information processing. There has been considerably little focus on the properties of the tasks employed in regard to interpreting the experimental findings (with the exception of Greenwald, 1972). Studies on intrahemispheric competition, although not explicitly relevant to the study of divided attention offer an important focus on the tasks employed in dual task experiments. Predictions of outcome are made in terms of a task property—i.e., the dimension concerning whether a given task primarily involves a control centre in the right or the left cerebral hemisphere. If both tasks require programming by control centres in the same hemisphere, then competition and performance decrement may occur.

The importance of intrahemispheric competition to research on divided attention can be understood within the framework of Duncan (1979), where the dual task environment is viewed as being different than the sum of its parts—i.e., the sum of the two single tasks (see above). Recall that Duncan made a case for the existence of "emergent processes" which occur in the dual task situation but not in regard to single task performance. According to Duncan, such processes can account for some of the research findings. He suggests that popular explanations, such as limited capacity, might be partly correct but cannot entirely explain the experimental results. After implicating some emergent processes within the areas of visual identification, response choice, and motor programming, Duncan comments that "once these are seen, a few moments' thought will suggest many others" (p. 227). In my view, intrahemispheric competition could well be one such emergent process. This process is not likely to exist in a situation where one simple task is performed. However, intrahemispheric competition may play a major role in some dual task pairings of fairly simple tasks. If intrahemispheric competition accounts for some portion of the findings in dual task studies but is not a relevant process in the single task environment, then it can be conceived as an emergent process which requires qualifications of explanations of research findings on divided attention. Furthermore, it is possible that older persons may have special problems in regard to intrahemispheric competition. Let us now examine the literature on intrahemispheric competition in regard to dual task performance.

The Functional Cerebral Distance Model

The impetus for research on intrahemispheric competition stems from the "functional distance" hypothesis. As stated by Kinsbourne and Hicks (1978), the hypothesis asserts that "the functional distance between any two cerebral control centers decreases with the extent to which they compete on discordant tasks" (p. 267). With respect to dual task performance of dissimilar tasks this implies that if both activities are programmed in the same cerebral hemisphere, performances will be inferior to those found when one activity is programmed on one side of the brain and one on the other side. This is because dual task performance of dissimilar tasks is hypothesized to worsen to the extent that the cerebral programs which control the two performances share the same functional space.

Studies on the topic of intrahemispheric competition are a subset of the research on a more general model—Kinsbourne's "functional cerebral distance model." At this point it is instructive to quote Kinsbourne on an explication of his model. The more specific intrahemispheric competition hypothesis (more interference for simultaneous performance of two dissimilar tasks when programmed in the same hemisphere versus separate hemispheres) is better understood within the context of the functional cerebral distance model. The model is summarized below by Kinsbourne (1979):

> Functional cerebral distance is an inverse function of neuronal connectedness. Cerebral distance is least between points that are highly linked, more directly interconnected, greater between sparsely or indirectly linked points. Let us suppose that a person is given a task, his 'main' task, which calls for specifically patterned cerebral activation at a certain locus in the brain. We assume that the pattern of activation, though maximal at that locus, will spread in a monotonically decremental fashion across functional cerebral space. Now suppose that the subject performs, at the same time, a second task which is correlated with the main task. Its locus of programming (maximal cerebral activation) may either be close to that of the main task or further away. At the locus of the secondary task there already exists a footstool of congruently patterned excitation. If that locus is close to that of the main task, relatively little extra programming is needed. If it is far distant, the secondary task will require more additional programming. So with correlated tasks (the

> same superordinate routine programmed concurrently by different parts of the brain), it helps if they are localized close together. If they are far apart in functional cerebral distance, then little savings derive from the excitation generated by the main task. In other words, if you ask the subject at the same time to do the same thing with two separate output organs, the model predicts better performance if their cerebral representations are juxtaposed in functional cerebral space. But uncorrelated tasks are best done if the loci in question are far apart. Then only a minor inhibitory barrier between the main task program and the second task program is required, to permit the latter to run its course uncontaminated by interfering cross-talk. However, if the loci are close together then it is necessary to generate massive interpolated inhibition to counteract the vigorous competition of the two patterns of brain activation. That is the functional cerebral distance principle. (pp. 6-7)

Kinsbourne explains that many predictions can be based on the above model. He divides his predictions into "priming effects" and "concurrent effects." Priming effects are "the effects of inducing a certain mental set on a subsequent performance," while concurrent effects "arise in dual-task performance." The model accounts for two classes of concurrent effects—one class of effects involving correlated or similar tasks, and the other concerning uncorrelated or dissimilar tasks. As for similar tasks, closeness in cerebral functional space facilitates performance. However, such closeness in cerebral functional space promotes interference on dissimilar tasks. This is where the notion of intrahemispheric competition comes into play. Dissimilar tasks are interfered with to a greater extent if they are both programmed in the same hemisphere (closer cerebral functional space).

Evidence of a Commissurotomized Patient

The bulk of communication between the two hemispheres takes place through a bundle of nerve fibers called the corpus callosum. If a person's corpus callosum is severed, it follows that such a person can provide information enabling clearer inferences on hemispheric functioning relative to studying the behavior of normal subjects. Studies of patients who have had their corpus callosum severed as treatment for intractable epileptic seizures therefore have captured the attention of neuropsychologists. One such study (Kreuter, Kinsbourne, & Trevarthen, 1972) provides evidence that bears directly upon the issue of intrahemispheric competition.

Kreuter et al. subjected one of their five commissurotomy patients to several tests of dual task performance. The patient, a 37-year-old, right handed woman of low average intelligence, was selected as the only one of the five patients suitable for these tests in regard to hemispheric functioning. This is because her speech and manual functions were little affected by cerebral pathology and she showed no signs of weakness or dyspraxia in either hand at the time of testing. When the patient, referred to as N.G., was operated on at age 30 she had already a high degree of cerebral lateralization of speech and manual functions. Furthermore, she had little post-operative adjustment of functions and little bilateralization of control of voluntary hand use. Hence N.G. was considered a highly suitable subject for experiments on hemispheric functioning in a dual task environment.

Synchronous tapping of the right and left index fingers was paired with several verbal and computational tasks which varied in difficulty. N.G.'s performance was compared with a control group of normal subjects. These control subjects showed no disruption of rhythm of tapping during concurrent verbalization, and they completed the verbal and computational tasks without error.

The verbal tasks consisted of reciting the alphabet aloud, reciting it by skipping alternate letters (A,C,E, etc.), and reciting the alphabet backwards. When N.G. was asked to tap both fingers simultaneously while reciting the alphabet, she experienced no difficulty with either task. However, when asked to tap and at the same time recite the alphabet skipping alternate letters, her performance differed markedly from the control group. Although there was little change in the left hand response (controlled by the right hemisphere), the right hand (programmed by the left hemisphere) stopped tapping. Only during periods when the task was not attended to did the right finger respond. Kreuter et al. note that within the bursts of tapping by the right hand, the taps were not synchronous with the left hand but were at a higher rate. As for reciting the alphabet backwards while tapping, N.G. could not do this as on each trial she made mistakes throughout while both fingers stopped tapping. During spontaneous conversation after failing on this test, N.G. continued to tap with her left finger while right tapping came to a halt.

N.G. was able to solve simple arithmetical problems (e.g., 3 x 2, 6 ÷ 3) while tapping, but she was unable to maintain synchrony in her tapping. Tapping frequency was greater for the right hand than the left hand. N.G. then was asked to solve complex arithmetical problems (e.g., 3½ x 2, 4½ - 2¼) while tapping. The control subjects could perform the tasks adequately, and even when they hesitated and fumbled for the correct answers their tapping pattern remained constant. N.G. was unable to solve any of these problems, found it very difficult to coordinate her hand movements, and was especially impaired with her left hemisphere controlled right hand. Kreuter et al. report that N.G. generally responded with the right hand only while the problem was being presented or in between trials and not when she was thinking how to respond.

To summarize, the control subjects could perform adequately on both tasks in each of the dual task pairings. N.G. could perform well only when the simplest verbal task was paired with tapping. With moderate task difficulty, right (but not left) finger tapping was disrupted while thinking about the answer. With the most difficult tasks, N.G. began to make mistakes and tapping stopped on both sides.

In explaining their findings, Kreuter et al. refer to the functional distance hypothesis: "Concurrent activities of sufficient difficulty (i.e. at a sufficiently high level in a hierarchy of brain functions) will compete in proportion to the extent to which their cerebrally located neural programs share the same functional space, such as one hemisphere (in this case the left). Commissurotomy increases this form of intrahemispheric functional competition, presumably because it eliminates the option of programming control bihemispherically" (p. 460). While Kreuter et al. conclude that concurrent activities maximally compete when programmed in the same hemisphere, they comment that the disconnected hemispheres draw upon the limited and still unified attentional resources of the brain as a whole. Kreuter et al. point out that with difficult tasks both fingers were disrupted, and conclude that "a maximum effort by one hemisphere does withdraw capacity from the other, an effect which in the absence of the callosum is presumably mediated by a 'capacity distributing system' located in the brain stem" (p. 460).

Research with Normal Subjects

The notion of intrahemispheric competition, stemming from the functional distance model, has been examined for the most part in regard to vocal-manual interactions. Before reviewing this research it should be mentioned that a few studies (e.g., Cohen, 1970; Briggs & Kinsbourne, 1976) have focussed on interactions between limbs, which can serve to add generality to the research findings. For example, Briggs and Kinsbourne (1976) used all possible pairings of the four limbs in concurrent dual-limb step-tracking tasks of a dissimilar nature and found support for the functional distance model. Errors were least frequent for diagonal limb pairings (most functional distance), intermediate for ipsilateral limb pairings, and most frequent for contralateral homologous pairings (least functional distance). The same pattern of results was obtained for speed of responding. The opposite finding has been reported in dual-limb research involving tasks of a similar nature and in studies of transfer of training. These investigations (reviewed by Kinsbourne, 1979) support the prediction of better performance for similar tasks when there is less functional distance.

The seminal study on intrahemispheric competition is regard to vocal-manual interactions was carried out by Kinsbourne and Cook (1971). The authors required their right handed, young adult subjects to balance a wooden dowel rod on the index finger while speaking (i.e., listening to a sentence and repeating it aloud continually). The rod was balanced either on the right or the left index finger, and performance (balancing duration) was compared to balancing without speaking. Kinsbourne and Cook found that the concurrent speech disrupted balancing on the right hand but not on the left hand. This finding is consistent with the intrahemispheric competition model, as speech and right handed motor control both are thought to be controlled primarily by the same (left) hemisphere (Brinkman & Kuypers, 1972; Gazzaniga, 1970; Rasmussen & Milner, 1975; Zangwill, 1967).

Kinsbourne and Cook's finding of asymmetrical right sided decrement in cognitive-manual task pairings has been replicated extensively. Hicks (1975) found that when the phonetic difficulty of the verbalized phrases was increased (tongue twisters instead of ordinary words) there was greater decrement on right handed balancing but not on left handed balancing. Botkin, Schmaltz and Lamb (1977) had right handed subjects perform a motor task with the left arm or with the right arm while simultaneously performing a digits-backward task, and found that subjects in the left arm group performed significantly better on the digits-backward task. Briggs and Kinsbourne (1974) combined multi-limb tracking with verbal shadowing and found that more errors were made with the right sided than with the left sided limbs. Likewise, Briggs (1975) found more right hand than left hand errors when a bimanual step-tracking task was performed concurrently with a verbal task. Hicks, Bradshaw, Kinsbourne and Feigin (1977) and Hicks, Provenzano and Rybstein (1975) used finger-sequencing tasks and found similar results with concurrent verbalization.

Kinsbourne and Hiscock (1977) and Kinsbourne and McMurray (1975) extended the findings of asymmetrical right sided decrement to children. Kinsbourne and McMurray paired finger tapping with reciting a nursery rhyme or repeating the names of familiar animals. Their study was replicated by Hiscock and Kinsbourne (1978, 1980) with children aged 3 to 12 years and it was found that vocalization disrupted right hand tapping more than left hand tapping. Hiscock and Kinsbourne (1980) concluded that their results support a developmental invariance hypothesis of language lateralization since the degree of asymmetry did not vary with age (one year longitudinal data as well as cross-sectional data). Hiscock and Kinsbourne also found that whereas group data are stable over time, individual asymmetry scores are relatively unreliable.

It has been pointed out that sex may be related to hemispheric specialization (e.g., Piazza, 1980). If this is the case, one could expect sex differences in the experiments on vocal-manual interactions in the dual task paradigm. At present the literature is not conclusive. Hiscock and Kinsbourne (1980) reported that recitation of a nursery rhyme interfered asymmetrically with the tapping of boys but not girls.

However, their animal names task did not reveal a sex difference and neither task resulted in a sex difference in a previous study (Hiscock & Kinsbourne, 1978).

Kinsbourne and McMurray (1975) and Piazza (1977) indicated that while verbalization disrupted right finger tapping more than left tapping, verbalization reduced tapping rates on *both* sides. This is inconsistent with the enhanced performance on the left hand (dowel rod balancing) that was reported by Kinsbourne and Cook (1971). Hicks, Provenzano and Rybstein (1975), using finger sequencing tasks in which either the right or the left hand would lead the sequence, obtained results like those of Kinsbourne and McMurray and Piazza—decrements on both sides. Hicks et al. attribute this to the fact that different and more difficult tasks were used in their study than in previous experiments, and that their tasks had greater cognitive components.

Unless otherwise stated, all of the described experiments are based on right handed subjects. Left-handers, ambidextrous persons and those with mixed handedness are studied separately and less frequently, as they show either no distinctive pattern of hemispheric specialization (bilateral representation) or the opposite lateralization pattern of more left sided decrement (Piazza, 1980). For example, Hicks (1975) found that concurrent verbalization shortened the rod balancing duration of both hands for left handed subjects.

Much has been written about the asymmetric effects of cognitive tasks on motor performance, but what about effects of concurrent motor tasks on cognitive performance? Hicks (1975) found that when the phonetic difficulty of verbalized phrases was increased (tongue twisters instead of ordinary words) with concurrent rod balancing, more verbalization errors occurred on trials with the right hand but not with the left hand. On the other hand Bowers, Heilman, Satz and Altman (1978) did not find any interference effects on the cognitive tasks. Hiscock and Kinsbourne (1980) reported that interference between tasks was mutual but not symmetric. They obtained a 4% decrease in verbal production relative to baseline verbal output while the tapping rate decreased by about 19% relative to the baseline rate. Nevertheless, differences between right hand tapping and left hand tapping in the suppression of verbal production were not significant. Hiscock and Kinsbourne suggested that an asymmetric effect of tapping upon speech production could be demonstrated if subjects were instructed to allocate higher priority to tapping than to talking. Bowers, Heilman, Satz and Altman (1978) relate the lack of mutual asymmetric interference between tasks to the intrahemispheric competition hypothesis:

> One cannot predict from the intrahemispheric competition hypothesis whether excitation of two proximal brain areas will result in mutual interference, or whether the interference will be one-sided. As indicated from our data, performance on each of the cognitive tasks was unaffected by ongoing motor tapping, although motor activity was disrupted by the cognitive tasks. Since the motor and cognitive tasks did not mutually interfere with each other, it appears that a one-way street phenomenon exists, with cognitive tasks having priority over motor systems. This one-sided interference, however, cannot be predicted within the framework of Kinsbourne's model. Nevertheless, this model is tenable if one assumes a hierarchical arrangement with higher order systems interfering with lower order systems but not vice versa. (p. 555)

With some qualifications, it appears that the intrahemispheric competition hypothesis is generally supported for verbal-manual interactions (greater right sided decrement). What are the findings for nonverbal tasks? The logical prediction is greater left sided decrement since a nonverbal task, presumably mediated by the right hemisphere, should interfere more with left sided motor performance which involves the same (right) hemisphere.

Piazza (1977) found that when subjects hummed concurrently with finger tapping, humming disproportionately reduced tapping on the left finger in each of three age groups (3-, 4-, and 5-year-old children). Other studies supportive of the intrahemispheric competition hypothesis for nonverbal tasks are not easy to find.

Summers and Sharp (1979) had subjects finger tap concurrent with a memory task. The memory task was either verbal (reporting as many letters in a matrix as possible in any order) or spatial (reporting the location of the circles in a matrix), or the task was combined to be a verbal-spatial task (indicating both the location and identity of the letters in the matrix). Although there was a significant reduction for the spatial condition in recall from left hand tapping but not right (consistent with Kinsbourne's model), tapping decreased for the right hand but not the left as compared to control tapping (inconsistent with Kinsbourne's model). Summers and Sharp commented that the spatial task was more demanding than the verbal task, and that subjects may have used verbal mediation to aid retention of the material.

McFarland and Ashton (1978) employed six verbal and six nonverbal tasks in their research. They obtained the usual findings for each of their verbal tasks (greater right sided than left sided decrement on the motor task). The motor task required the subject to successively press two keys with either the right or left hand. The nonverbal tasks consisted of two scanning tasks, two closure tasks in which the subject had to identify a picture or a printed word, an embedded figures task, and a task in which the subject had to match segments of a line drawing to the pattern of a completed picture in order to identify any missing pieces. Overall, the nonverbal tasks resulted in a bilateral and generally symmetrical decrement in dual task tapping relative to tapping only. None of the six nonverbal tasks revealed the predicted pattern (greater left sided than right sided decrement on the motor task). McFarland and Ashton concluded that the factor of task difficulty was not responsible for the different outcomes on the verbal and nonverbal comparisons. They reasoned that there are three plausible explanations for their finding of bilateral decrement on the nonverbal tasks: "the nonverbal tasks were processed to some extent by both hemispheres; the hemispheres are not equally potent in their control of the hands for the tapping task used; the variable of task difficulty may have the multidimensional components which affect subjects' estimates of the difficulty of verbal and nonverbal tasks" (p. 108).

Bowers, Heilman, Satz and Altman (1978) included a facial recognition task along with finger tapping in their series of concurrent task conditions. Like McFarland and Ashton (1978), they found bilateral and symmetrical decrement from baseline tapping, with the right hand remaining superior to the left under the dual task condition involving facial recognition. Bowers et al. reasoned that "(a) the faces were mediated bilaterally (via verbal tagging, etc.); or (b) the faces were right hemisphere mediated, but their processing did not overlap with motoric programs of the same hemisphere. . . . If so, then simultaneous nonverbal-motor performance should entail less of an overlap in 'functional space' than simultaneous verbal-motor performance. . . . Our findings, therefore, . . . are compatible with an intrahemispheric competition model" (p. 554).

Kinsbourne (personal communication) has offered several reasons why it has been difficult to find support for the intrahemispheric competition hypothesis via nonverbal tasks: (1) most nonverbal tasks have at least some degree of a verbal component; (2) even if a task is purely nonverbal there may be verbal thinking during attention lapses throughout task performance; (3) perhaps the right hemisphere is not as strongly specialized for nonverbal processing as the left hemisphere is for verbal processing.

Thus far we can see that there is considerable support for the intrahemispheric competition hypothesis for verbal-manual interactions, and that the lack of support from studies of nonverbal-manual interactions may be explainable. Lomas (1980) points out that cognitive-manual interference effects may be much more specific than simply looking at which hemisphere is involved in processing. His research suggests that the control of movement transitions made with minimal visual guidance is an important variable, and that a system specialized for such control is involved with speech and contained in the left hemisphere. His main point is that interference effects must occur in functionally overlapping systems rather than simply being attributed to processing within the same hemisphere. This is consistent with Kinsbourne's more general functional distance model, from which the intrahemispheric competition hypothesis emanates. Nevertheless, it should be clarified that whether two tasks are processed within the same hemisphere is of secondary importance. The primary concern is whether the control centres for the two tasks are proximal in cerebral space (close functional distance). The intrahemispheric competition hypothesis represents one of several kinds of tests of the more general functional distance hypothesis.

Consistency with the Divided Attention Literature

To determine whether the intrahemispheric competition model is consistent with the divided attention literature, the ideal approach would be to categorize each of the experiments in terms of right-left, left-left, or right-right combinations of tasks in regard to their hemispheric localization. One would then summarize the main findings of each study and compare the results to predictions of the intrahemispheric competition model. Unfortunately such a procedure is not feasible. Since research on divided attention has been carried out without concern about hemispheric localization of the tasks employed, it is difficult if not impossible to identify tasks as primarily right or left hemisphere. Furthermore, it is becoming increasingly evident within the field of neuropsychology that to label a task as right or left hemisphere is not a clear and simple matter. (For example, hemispheric localization of function for a given task might change with practice and task familiarity.) Nevertheless, there are a few studies worth mentioning.

Hicks, Provenzano and Rybstein (1975) suggest that there are time sharing studies that are consistent with the intrahemispheric competition hypothesis, although the researchers did not interpret their experiments in this way. Hicks et al. are referring to the investigations of Allport, Antonis and Reynolds (1972), Greenwald (1972) and Greenwald and Shulman (1973). Allport et al., for example, paired verbal shadowing with processing complex visual scenes or sight reading piano music, and found little or no decrement relative to single-task performance. If one can entertain the assumption that verbal shadowing primarily involves the left hemisphere and that the visual processing and musical sight reading tasks are mainly right hemisphere, then Allport et al.'s findings are consistent with the intrahemispheric competition model. Little decrement occurred because the two tasks were localized in different hemispheres.

In Greenwald's (1972) experiment, there were tasks involving either high ideomotor (IM) compatibility or low IM compatibility. High IM compatibility was operationalized by requiring subjects to say the word "right" or "left" in response to hearing "right" or "left" (respectively), or by having subjects move a switch right or left in response to seeing an arrow pointing right or left. The former task involves a verbal stimulus and a verbal response, while the latter task consists of a nonverbal stimulus and a nonverbal response. Low IM compatibility required either saying the word "right" or "left" in response to viewing an arrow move right or left (respectively), or moving a switch right or left in response to hearing "right" or "left." These tasks involve either a verbal stimulus combined with a nonverbal response, or a nonverbal stimulus with a verbal response. If one allows that verbal and nonverbal functions are concentrated in different cerebral hemispheres, then it becomes apparent that Greenwald's findings are compatible with the intrahemispheric competition hypothesis. This is because pairings of two high IM compatible tasks result in one verbal (left hemisphere) task and one nonverbal (right hemisphere) task, and these pairings provided little difficulty for the subjects. Combining two low IM compatible tasks creates two tasks which are both verbal and nonverbal, and hence both tasks require involvement from both hemispheres. Subjects had considerable difficulty in this situation.

Greenwald did consider the intrahemispheric competition model as a possible interpretation of his findings. He comments that "the efficiency with which the two decisions were performed simultaneously may have depended in part on whether stimulus analysis and response selection functions could be isolated in separate hemispheres (High Ideomotor Compatibility) or required coordinated action of both hemispheres for each task (Low Ideomotor Compatibility)" (p. 57). However, Greenwald did not entirely accept this interpretation due to the findings of

Schvaneveldt (1969), who used a "pure" verbal task simultaneous with a pure nonverbal task and found relatively inefficient time sharing. Greenwald concluded that "this hypothesis may have more value in explaining the difficulty of time sharing in the Low Ideomotor Compatibility condition than in accounting for the efficiency of the High Ideomotor Compatibility condition" (p. 57). Incidentally, Kantowitz and Knight (1976) report a failure to replicate portions of Schvaneveldt's results, possibly due to difficulties with counterbalancing.

In contrast to many of the studies on divided attention, Lindsay and Norman (1969) found no decrement in dual versus single task performance when a short term recognition memory task was paired with a moderately difficult signal detection task. In the memory task each trial consisted of six three-digit numbers presented to the right ear at a rate of one number every second. A test number was presented at the end of the list and the subject's task was to indicate, with a confidence rating, whether or not the test number had been presented. The detection task involved a tone embedded in white noise and the subject had to indicate which one of four noise bursts did not contain a signal. Again, let us make assumptions about hemispheric localization. If the memory task primarily involved the left hemisphere (as information was presented to the right ear) and the detection task involved the right hemisphere (as the stimulus was nonverbal), then efficient dual task performance is an entirely reasonable outcome wince there would have been little intrahemispheric competition. Detection performance was unaffected by the task requirement, and memory performance was impaired only when the signals in the detection task were very difficult to detect.

The aforementioned studies appear to be consistent with the notion of intrahemispheric competition and the more general functional distance hypothesis. Admittedly, it is speculative to label the tasks in these studies as right or left hemisphere. In any case, it would seem that the intrahemispheric competition hypothesis is worthy of consideration in regard to studies of divided attention. The present research interest of this author is to study age differences in divided attention while considering the role of intrahemispheric competition.

Statement of the Problem

The literature on divided attention, age differences in divided attention, and the intrahemispheric competition hypothesis have now been extensively reviewed. It is clear that divided attention is particularly relevant to the study of adult age differences in cognitive performance and, with regard to divided attention in general, it appears that intrahemispheric competition may represent a modifying variable. In response to Craik's (1977) call to investigate the nature of the age decrement in divided attention situations, this author has chosen to focus on the role of intrahemispheric competition as there has been no investigation of adult age differences in this area.

The main purposes of this study were: (1) to further investigate age differences in divided attention in general; (2) to further research the intrahemispheric competition hypothesis (which is a specific test of the more general cerebral functional distance hypothesis); and (3) to determine whether there are age-related effects specifically in regard to intrahemispheric competition. Although all three purposes are important to this author, it is the latter topic that provided the major impetus for research as adult age differences in intrahemispheric competition have not been addressed. The following research was conducted to provide information relevant to the three aforementioned concerns.

CHAPTER 2

PILOT EXPERIMENTS

The focus of the pilot research was on replicating Kinsbourne's findings of intrahemispheric competition and developing suitable procedures to use in the primary experiment. A variety of tasks were employed in order to explore effects of some tasks that had not yet been used as well as previously used tasks, and to enable the investigator to utilize the most appropriate tasks in the primary experiment.

The pilot research will be mentioned only briefly. Although some of the findings seem clear, the procedures and results will not be elaborated due to exigencies of the pilot investigations which detract from experimental control, such as refining procedures from subject to subject. For example, it was discovered that for some tasks visual presentation of stimuli was preferable to auditory presentation. The wording of instructions often was altered to improve clarity. Intertrial intervals were changed. Such alterations provided the basis for the procedures used in the main experiment.

The effects of a variety of nonverbal concurrent tasks were explored. These tasks included facial recognition, recurring geometric nonsense figures, figure recognition, figure reproduction, colour matching, and a spatial orientation task. The facial recognition task was based on the Benton Facial Recognition Test. The task involving recurring geometric nonsense figures was derived from Kimura's Recurring Figures Test and involved making judgments on whether a given figure had been presented before. The figure recognition and figure reproduction tasks consisted of figures from the Recurring Figures Test. Both tasks required the subject to carefully study a group of figures while tapping. Immediately after tapping, the subject was asked to indicate which figures of a second group were the same as in the first group (recognition), or to draw a certain figure indicated by its number (reproduction). The colour matching task involved viewing a group of very similar colours and, immediately after tapping, making a judgment on which colours were the same. The spatial orientation task required right-left discriminations for a variety of orientations of stick figures of a man.

All pilot subjects were college students, most of them males. For five of the nonverbal tasks there was virtually no change from control tapping performance with either hand. For one task (figure reproduction) there was slight bilateral decrement. The absence of asymmetric decrement for the nonverbal tasks is consistent with the literature.

Verbal concurrent tasks included silent reading, a verbal fluency task, and repeating tongue twisters. The silent reading task required the subject to read a paragraph passage from the Logical Memory subtest of the Wechsler Memory Scale while tapping, and subsequently to answer three multiple choice questions about the passage. This task was employed by Bowers, Heilman, Satz and Altman (1978), except they utilized a subsequent recall test rather than a recognition test. Whereas Bowers et al. found greater right handed than left handed tapping decrement compared to control tapping, this investigator found no decrement with either hand. This is probably due to the recognition test being used instead of recall.

The verbal fluency task was the same as that used by Bowers et al. Subjects had to utter as many words as they could think of that began with a specified letter. The result was the same as for Bowers et al.—greater right handed than left handed decrement, and little decline on left handed tapping. Similar results were obtained with a tongue twister task except decrement, while asymmetrical (more on the right hand) occurred with both hands and to a greater degree than with the verbal fluency task. Decrements in cognitive performance on the concurrent tasks were not found for any of the verbal or nonverbal tasks.

The right sided asymmetry for the verbal fluency and tongue twister tasks was found for both 30- and 20-second trials, and is supportive of Kinsbourne's intrahemispheric competition hypothesis. Tongue twisters consistently resulted in more overall interference with tapping than any other task. Since both the tongue twister and verbal fluency tasks revealed right sided asymmetrical decrement, it was decided to use these tasks in the primary experiment. An additional task, sentence repetition, was not investigated in pilot research but was included in the main experiment to provide another level of task difficulty (supposedly low) for a verbal, vocal concurrent task.

CHAPTER 3

THE PRIMARY EXPERIMENT

Introduction

The primary experiment was designed to (1) replicate previous findings pertaining to the intrahemispheric competition hypothesis and the more general cerebral functional distance model; (2) to assess adult age differences in divided attention; and (3) to determine whether there are age differences particularly with regard to the effects of intrahemispheric competiton. Two groups of subjects, aged 16 to 29 years and 65 to 83 years, were tested.

A manual-verbal dual task paradigm was used in which subjects performed a single repetitive finger tapping task with the right or left index finger for 20 seconds and, at the same time, performed a verbal task which required vocalization. The concurrent tasks were tongue twisters (repeating a phonetically difficulty phrase), verbal fluency (saying as many words as one could think of that began with a certain letter), and sentence repetition. Tapping performance during each concurrent task condition was compared to control tapping (tapping without a concurrent task).

At this point a notation system will be introduced to abbreviate the tasks which are frequently referred to throughout this text:

C — Control (tapping only)

TT — Tongue Twister task concurrent with tapping

VF — Verbal Fluency task concurrent with tapping

SR — Sentence Repetition task concurrent with tapping

The independent variables in the primary experiment were age (2 levels), task (4 levels), and hand (2 levels). The dependent variables were the number of taps during the 20-second trial for the right index finger and left index finger for each of the four task conditions. Dependent measures were taken with regard to cognitive performance on the concurrent tasks but this is viewed as of secondary importance, based on previous research findings as well as on results of this author's pilot investigations. Task orders were counterbalanced, and hand orders were counterbalanced within each of the task order conditions.

Hypothesis One

Compared to control task performance (tapping only), concurrent task conditions result in greater tapping decrements for older persons than for younger adults, regardless of hand.

The consistent literature on age-related effects of divided attention, reviewed in chapter one, is the basis for this hypothesis.

Hypothesis Two

Compared to control task performance (tapping only), concurrent verbal task conditions produce greater right handed than left handed tapping decrements.

This hypothesis is based upon the numerous research findings mentioned in chapter one as well as upon the pilot studies of the present author. Support for this hypothesis is support for the intrahemispheric competition hypothesis and the more general cerebral functional distance model.

Hypothesis Three

There are age differences in the degree of the effects of intrahemispheric competition such that older persons show greater functional asymmetry (more right than left handed decrement) than younger adults during concurrent verbal task conditions.

This is an exploratory hypothesis as the literature provides no clear basis for a prediction in one direction or the other. Kinsbourne (personal communication) has suggested that special age-related deficits in intrahemispheric competition might occur as a result of the increasing connectedness of the brain with age. As there is an increasing loss of inhibitory neurons the control centres might be more closely connected for the tasks involved in intrahemispheric competition situations. This would result in greater interference for dissimilar tasks.

Support for hypothesis three would suggest that the elderly have special difficulties under conditions of intrahemispheric competition. Such a finding could be related to the increasing connectedness of cerebral control centres and/or to the possibility of an age-related increase in lateralization. On the other hand, a finding of no age differences in the pattern of effects of intrahemispheric competition would be consistent with a developmental invariance hypothesis (Hiscock & Kinsbourne, 1980).

Method

Subjects

The subjects were 48 male volunteers. Twenty-four were elderly and had a mean age of 72.3 years (range 65 to 83 years). They were members of a senior citizens group in Victoria, British Columbia and were initially contacted through requests for volunteers made by the researcher at a meeting of their organization. The other 24 subjects were younger, with a mean age of 19.1 years (range 16 to 29 years) and included mostly high school students in grade twelve and some volunteers from the YMCA. College students were not included in the research due to concerns about an education bias relative to the older group of subjects. The elderly subjects had a mean education of 11.83 years (range 6 to 19 years, median = 11.0). The mean education for the younger subjects was 12.08 years (range 10 to 16 years, median = 12.0).

Subjects were asked to indicate their general state of health, and only subjects who indicated good health were included in the experiment. It was especially important that arthritis was not present in the hands, as this would affect performance on finger tapping. Three of the elderly volunteers were excluded from the study on the basis of arthritic conditions. All subjects were fully ambulatory and living in their own homes or apartments.

Subjects completed a brief handedness inventory in order to distinguish between moderately and strongly right handed subjects, and to exclude left handed subjects as well as those with mixed handedness or ambidexterity. Five volunteers were excluded from the experiment, while subjects who indicated they were at least moderately right handed were included. Finally, only male subjects were included in the primary experiment. This is because the research evidence pertinent to sex differences in intrahemispheric competition is not yet clear (Hiscock & Kinsbourne, 1980).

Tasks

The tapping task required subjects to tap as rapidly and consistently as possible with either the right or left index finger for a 20-second period. In some trials subjects tapped while doing nothing else (control) and other trials involved tapping concurrent with another task (TT, VF, or SR). The finger tapping task was employed since it has been viewed as a sensitive measure of assessing contralateral hemispheric functioning (Bowers, Heilman, Staz, & Altman, 1978; Summers & Sharp, 1979).

The tongue twister (TT) task required the subject to repeatedly vocalize a tongue twister phrase and to utter the phrase both rapidly and accurately. Two tongue twisters were used in the experimental trials (one for the right hand tapping trial and one for the left hand trial). The tongue twisters were selected from a collection by Schwartz (1972) and were reportedly of equal difficulty.

For the verbal fluency (VF) task, subjects uttered as many words as they could think of, excluding proper names and direct derivatives, that began with a specified target letter. The target letters were selected from the list used by Bowers et al. (1978) to avoid using letters of widely varying frequencies.

The sentence repetition (SR) task employed simple sentences consisting of eight or nine words. Subjects were asked to repeat a sentence uttered by the experimenter, at which point another sentence would be given by the experimenter and subsequently repeated by the subject, and so on until the end of the trial. The sentences were derived from the Sentence Repetition Test used in the University of Victoria Neuropsychology lab. The task stimuli for the TT, VF, and SR tasks are presented in Appendix A.

Apparatus

The finger tapping apparatus consisted of a telegraph key mounted in the upper centre of a 29.2 x 11.5 cm wooden base. The knob on the key was 2.7 cm in diameter and was suspended 2.5 cm above the board. The gap between key contacts was adjusted to about 0.1 mm and the spring tension was set so that a force of approximately 20 g was necessary to close the contacts. Black tape was looped over the top of the key to restrict finger movements to within 1/2 inch of the key. The tapping apparatus was attached to a timed counter that mechanically advanced each time the lever was depressed and ceased advancing upon elapse of the specified trial time (20 seconds for the experimental trials and 10 seconds for practice trials). Intertrial intervals were timed using a Hanhart stopwatch.

Procedure

All subjects were seen individually by the experimenter by appointment. The 24 older subjects were tested in one of the rooms at a senior citizens' centre. The majority of the younger subjects (N = 18) were tested in a room at a high school. The other subjects were tested at their places of employment. In all instances the rooms in which the experiment was conducted met the requirements of being reasonably quiet, well illuminated, and free from interruption.

Subjects were seated at a table with the experimenter on the other side. The finger tapping apparatus and a vision barrier (to block the subjects' view of test materials) were on the desk.

Following a brief interview in which data on age, health status, and handedness (see Appendix B) were gathered, the subjects were introduced to the experimental tasks. Instructions (see Appendix C) were read to the subjects, after which they performed each of the four tasks alone (tapping, tongue twisters, verbal fluency, and sentence repetition) for the purpose of familiarization. Performance on these practice trials was not recorded. All subjects had one 20-second practice trial on each verbal task (SR, TT, and VF, presented in that order).

Following familiarization with the verbal tasks subjects were introduced to the finger tapping task. These were four 10-second trials alternating with the right and left index fingers. Half the subjects within each task order condition (to be elaborated later) tapped with the right index finger first (RLRL) while the other half of the subjects tapped with the left index finger first (LRLR). Subjects began all subsequent blocks of experimental trials with the same hand they first used for the practice trials. The subjects were instructed to tap as rapidly and consistently as possible with the index finger, and to restrict movement from the key (black tape was looped over the key and not more than 1/2 inch over the index finger for this purpose). The wrist and remaining fingers were kept still and positioned on the wooden base, and the entire forearm was positioned on the table. Subjects adjusted the orientation of the board when changing hands.

After the subjects had been introduced to the four tasks the instructions for the experimental trials were given (see Appendix C). All subsequent trials were of 20 seconds duration. There were seven blocks of two trials (one with the right hand and the other with the left). Four of the blocks were control trials (tapping only), and these were evenly spaced throughout the experiment. The remaining three blocks consisted of one block for each of the concurrent task trials (SR, VF, and TT) in which subjects were instructed to divide their attention equally between finger tapping and the verbal task. The task and hand orders were counterbalanced as shown in Figure 1. Subjects were equally distributed throughout the six order conditions for both age groups. Intertrial intervals were 30 seconds and the experimenter did not engage in conversation with the subjects during these invervals.

On completion of the experimental trials the purpose of the experiment was explained and questions were answered. It was requested that the subjects not divulge any information about the experiment to other individuals who were yet to participate as subjects.

FIGURE 1. Counterbalanced task and hand orders

Order 1	Order 2	Order 3	Order 4	Order 5	Order 6
C R L	*C* L R	*C* R L	*C* L R	*C* R L	*C* L R
SR R L	*SR* L R	*TT* R L	*TT* L R	*VF* R L	*VF* L R
C R L	*C* L R	*C* R L	*C* L R	*C* R L	*C* L R
VF R L	*VF* L R	*SR* R L	*SR* L R	*TT* R L	*TT* L R
C R L	*C* L R	*C* R L	*C* L R	*C* R L	*C* L R
TT R L	*TT* L R	*VF* R L	*VF* L R	*SR* R L	*SR* L R
C R L	*C* L R	*C* R L	*C* L R	*C* R L	*C* L R

R = right index finger
L = left index finger

Experimental Design

The experiment was a three factor mixed design. Age was a between subjects factor with two levels (young, old). Hand and Task were within subjects factors. There were two levels for hand (right, left) and four levels for task (C, TT, VF, SR). Hand and task orders were counterbalanced within each age group, resulting in six order conditions with four young subjects and four older subjects in each of the six conditions. Although hand order (2 levels) and task order (3 levels) can be viewed as two additional within subjects factors, these conditions were not considered as essential factors of interest. The intent was to avoid confounding the results with order effects by counterbalancing.

The design can be somewhat reconceptualized for the purpose of different analyses. For example, when the percentage change from control score is the dependent measure of interest (instead of raw tapping score), Task is a three level factor (TT, VF, SR) instead of a four level factor since the control level is not relevant in this case. When difference scores (right minus left tapping) are the dependent measure for analysis, the Hand factor becomes irrelevant and the design becomes an Age x Task design where Task may have either three levels or four levels, depending on whether raw tapping or percentage change from control is the measure of interest.

Results

A variety of measures were employed in the analysis of tapping data. These include two nonparametric measures (discussed in the subsection on overview of results), raw tapping scores, percentage change from baseline (control) scores, and difference scores (right minus left tapping). Although not the primary focus of concern, data on performance of the concurrent verbal tasks are presented as well.

Overview

Since the tapping data will be comprehensively explored through different types of measures, it is instructive to begin by presenting the findings in the form of general nonparametric analyses. The "percent change from baseline" measure, utilized by Bowers, Heilman, Satz and Altman (1978) is useful for this purpose as well as for more detailed parametric analyses.

Bowers et al. computed percent change from baseline scores via the following formula: Baseline tapping - Dual task tapping/Baseline tapping. This controls for "any spurious inflation of differences due to the higher initial performance level of the preferred hand" (Bowers et al., 1978, p. 544). In the present study, baseline tapping for a given hand is based on a mean of four control trials spaced evenly throughout the experiment, and dual task tapping is based on one tapping trial for the concurrent task of interest.

Table 1 indicates the number of subjects, by age group and task, who showed greater right sided than left sided decrement from baseline or greater left sided than right sided decline, regardless of magnitude, for differences of 1% or more. Although some subjects had somewhat enhanced performance on one or both hands during dual task tapping, the

Table 1: Number of Subjects with Patterns of Asymmetric Tapping Change on Concurrent Tasks, by Age Group and Task, for Percentage Change from Baseline Scores

Age Group	Task	Percentage Change from Baseline		
		Greater R than L Decrement (or more L enhancement)	Greater L than R Decrement (or more R enhancement)	Less than 1% Difference Between Hands
All Subjects (N = 48)	TT	23	21	4
	VF	25	17	6
	SR	31	11	6
Young (N = 24)	TT	12	9	3
	VF	14	5	5
	SR	17	5	2
Old (N = 24)	TT	11	12	1
	VF	11	12	1
	SR	14	6	4

R = right hand
L = left hand

majority of subjects showed concurrent tapping decrements. Therefore the following results are discussed in terms of differential decrement, even though some subjects actually had differential enhancement. Differential changes of more right than left decline and less right than left enhancement are grouped in the same category since these patterns are regarded as similar. Likewise, asymmetric changes of more left than right decrement and less left than right enhancement are also grouped in the same category.

For both age groups combined, 65% of the subjects had greater right hand decrement for the SR task while 23% showed greater left hand decline and 12% had less than a 1% difference between hand decrements relative to control tapping. Of the 42 subjects who demonstrated asymmetric patterns of any magnitude of at least 1%, 74% had greater right hand decrement. This was significantly greater than the 26% who showed the opposite pattern of increased left hand decrement (chi^2 = 9.52, $p < .01$). Differences for the TT and VF tasks for all subjects combined were not significant.

With regard to the young subjects, 58% revealed greater right hand decrement for the VF tasks compared to 21% who had greater left hand decline and 21% with virtually no differential decrement. Of the 19 subjects with asymmetrical change from baseline, 74% had greater right decrement than left decline (26%). This difference was significant (chi^2 = 4.26, $p < .05$). On the SR task 71% of the subjects had more right decline, 21% more left decline, and 8% showed little difference. Of the 22 subjects with asymmetrical change, 77% had greater right decrement than left decrement (23%), this difference was also significant ($\text{chi}^2 = 6.55$, $p < .02$), while differences were not substantial on the TT task.

For the older subjects there was a trend of greater right decrement on the SR task ($\text{chi}^2 = 3.20$, $p < .10$). Differential change from baseline did not approach significance for the VF and TT tasks.

Age comparisons indicated no substantial differences in asymmetric change from baseline. However, there was a trend of greater right and less left decrement for young subjects compared to older subjects in regard to the VF task ($\text{chi}^2 = 2.91$, $p < .10$).

Another nonparametric analysis of interest involves the number of standard deviations a subject's raw tapping score in a concurrent task condition is away from his mean control score. If a subject's tapping score were found to be at least two standard deviations (SDs) below the mean for his control score (based on four observations per hand), then his performance for the given hand would be considered significantly impaired. Performance would be regarded as significantly enhanced if a concurrent tapping score was at least 2 SDs above a control mean.

Table 2 presents data on subjects who showed bilateral, unilateral, or no dual-task tapping decrement based on the aforementioned criterion of at least 2 SDs decrement from control tapping for the given hand. Unilateral decline is subdivided into right only and left only.

Brief inspection of the bilateral and no decrement columns reveals that the TT task is associated with the most interference with tapping. The VF and SR tasks also resulted in tapping interference albeit to a

Table 2: Number of Subjects with Bilateral, Unilateral, or No Tapping Decrement on Concurrent Tasks, by Age Group and Task*

Age Group	Task	Decrement from Baseline*			
		Bilateral (R & L)	Unilateral R only	Unilateral L only	No Decrement
All Subjects					
(N = 48)	TT	27	8	8	5
	VF	10	10	5	23
	SR	10	7	1	30
Young					
(N = 24)	TT	15	4	3	2
	VF	4	6	1	13
	SR	3	4	0	17
Old					
(N = 24)	TT	12	4	5	3
	VF	6	4	4	10
	SR	7	3	1	13

R = right hand
L = left hand

*Decrement based on criterion of at least 2 SDs from control score for the given hand.

much smaller degree than the TT task. The SR task appears to have resulted in the least interference.

As for unilateral decline, the frequencies are too small for reliable statistical analysis but the trend seems to be greater right hand decrement for the VF and SR tasks, and no asymmetry on the TT task. Age comparisons do not reveal any substantial differences.

Table 3: Number of Subjects with Bilateral or Unilateral Tapping Enhancement on Concurrent Tasks*

Task	Enhancement from Baseline*		
	Bilateral	Unilateral	
		R only	L only
TT	1	0	2
VF	0	1	6
SR	0	1	3
Total Across Tasks	1	2	11

R = right hand
L = left hand

*All subjects. Enhancement based on criterion of at least 2 SDs from control score for the given hand.

Whereas Tables 1 and 2 focus on concurrent task tapping decrement, Table 3 focuses on tapping enhancement relative to baseline, based on the criterion of the tapping score being at least 2 SDs greater than the baseline score for the given hand. Results are not reported by age group since the frequencies are small and the patterns similar.

Table 3 indicates that, across all tasks, there were 14 cases of enhancement from baseline and only 1 of those cases involved bilateral enhancement. Of the 13 instances of unilateral enhancement, only 2 (15%) were of right tapping enhancement. This complements the aforementioned findings of greater right decrement.

To summarize the frequency data, it appears that asymmetry of change from baseline occurred for the SR task for young and old subjects and for the VF task for young subjects. Decrement seems to have been more bilateral for the TT task. The asymmetric pattern is one of greater right sided decrement and increased left sided enhancement compared to baseline tapping performance. The most overall interference is associated with the TT task. The parametric analyses of the following sections will elaborate the above overview of the research findings.

Raw Tapping Scores

Raw tapping scores (number of taps during 20-second trials) were analyzed in a Task x Hand x Age analysis of variance for each of the three concurrent tasks. For example, analysis for the TT task was done by a Task (C, TT) x Hand (R, L) x Age (young, old) analysis of variance. Task and Hand were within subjects factors while Age was a between subjects factor. Although all four tasks (C, TT, VF, SR) could be included in one analysis of variance, such an analysis was considered to be of less interest than analyzing the results for each individual concurrent task relative to control performance.

For each analysis data for the within subjects factors violated the assumption of homogeneity of covariance, indicating lack of compound symmetry in the covariance matrix (Winer, 1971, p. 523). All tests of within subjects effects were made with degrees of freedom adjusted according to the procedure of Greenhouse and Geisser (1959).

Table 4 presents an overview of the raw tapping data while the analyses of variance for each concurrent task are summarized in Tables 5, 6, and 7. For each concurrent task condition there were main effects of Age, Task, and Hand ($p < .001$ for each factor). The Age effects indicate that young subjects tapped faster than older subjects. The Task effects reveal that the concurrent task conditions were associated with significantly lower tapping scores relative to control (tapping only). As for the Hand effects, subjects tapped faster with the right hand than with the left.

Table 4: Means of Raw Tapping Scores by Task, Hand, and Age*

Task	Hand	Age	
		Young	Old
C	R	101.0	92.2
	L	91.3	82.2
TT	R	88.7 (-12.2%)	76.3 (-17.2%)
	L	81.4 (-10.8%)	68.6 (-16.5%)
VF	R	97.6 (- 3.7%)	86.6 (- 6.1%)
	L	91.4 (+ 0.1%)	75.7 (- 7.9%)
SR	R	98.2 (- 2.8%)	86.8 (- 5.9%)
	L	90.8 (- 0.5%)	79.9 (- 2.8%)

*Percentage of change from control, based on group means of raw tapping scores for the given hand and task, is indicated in parenthesis.

Table 5: Summary Analysis of Variance on Raw Tapping Scores for Factors: Task, Hand, and Age, for the Tongue Twister (TT) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Age	1	5622.51	12.19	**
Error term	46	461.31		
Within Subjects[2]				
Task	1	8047.13	79.97	**
Task x Age	1	155.88	1.55	
Error term	46	100.62		
Hand	1	3596.67	52.12	**
Hand x Age	1	1.51		
Error term	46	69.01		
Task x Hand	1	68.88	3.25	*
Task x Hand x Age	1	.05		
Error term	46	21.19		
TOTAL	191	248.64		

*$p < .09$
**$p < .001$

[1] F values less than 1 not shown.

[2] All within subjects effects p values determined using degrees of freedom multiplied by the factor $\varepsilon = .729$ (Greenhouse & Geisser, 1959).

Table 6: Summary Analysis of Variance on Raw Tapping Scores for Factors: Task, Hand, and Age, for the Verbal Fluency (VF) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Age	1	5996.51	15.59	**
Error term	46	384.62		
Within Subjects[2]				
Task	1	716.88	20.21	**
Task x Age	1	223.17	6.29	*
Error term	46	35.47		
Hand	1	4079.30	83.06	**
Hand x Age	1	76.26	1.55	
Error term	46	49.11		
Task x Hand	1	19.38		
Task x Hand x Age	1	59.63	2.25	
Error term	46	26.47		
TOTAL	191	177.87		

*$p < .02$
**$p < .001$

[1] F values less than 1 not shown

[2] All within subjects effects p values determined using degrees of freedom multiplied by the factor $\varepsilon = .883$ (Greenhouse & Geisser, 1959).

Table 7: Summary Analysis of Variance on Raw Tapping Scores for Factors: Task, Hand, and Age, for the Sentence Repetition (SR) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Age	1	4850.13	12.37	**
Error term	46	392.23		
Within Subjects[2]				
Task	1	356.76	16.09	**
Task x Age	1	51.05	2.25	
Error term	46	22.74		
Hand	1	3476.51	55.89	**
Hand x Age	1	.13		
Error term	46	62.20		
Task x Hand	1	86.67	7.75	*
Task x Hand x Age	1	1.88		
Error term	46	11.18		
TOTAL	191	163.85		

*p < .01
**p < .001

[1] F values less than 1 not shown

[2] All within subjects effects p values determined using degrees of freedom multiplied by the factor ε = .602 (Greenhouse & Geisser, 1959).

For the VF condition there was a Task x Age interaction ($p < .02$). This interaction is depicted graphically in Figure 2 and reveals that, in the VF condition, older subjects had greater decrement from their own control performance relative to the decrement shown by younger subjects. There was a Task x Hand interaction in the SR condition ($p < .01$) and a trend towards such an effect in the TT condition ($p < .10$). Figures 3 and 4 portray these results, which reveal greater decrement from control for the right hand. There were no three-factor interactions.

Effects of order conditions were analyzed in a Task (C, TT, VF, SR) x Hand (R, L) x Order (1, 2, 3, 4, 5, 6) analysis of variance with Order as a between subjects factor. The results, summarized in Table 8, indicate that there was not a main effect of Order but an interaction effect of Order x Task did occur ($p < .02$). Inspection of Figure 5 reveals that tapping performance varied as a function of Order primarily for the TT task, where orders 3, 4, and 6 were associated with faster tapping scores relative to the other order conditions.

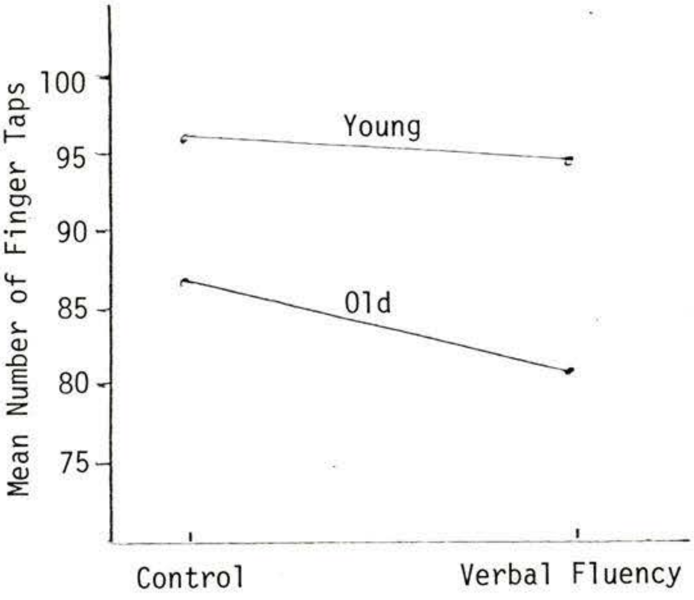

Figure 2: Mean number of finger taps during Control and Verbal Fluency conditions for Young and Old subjects.

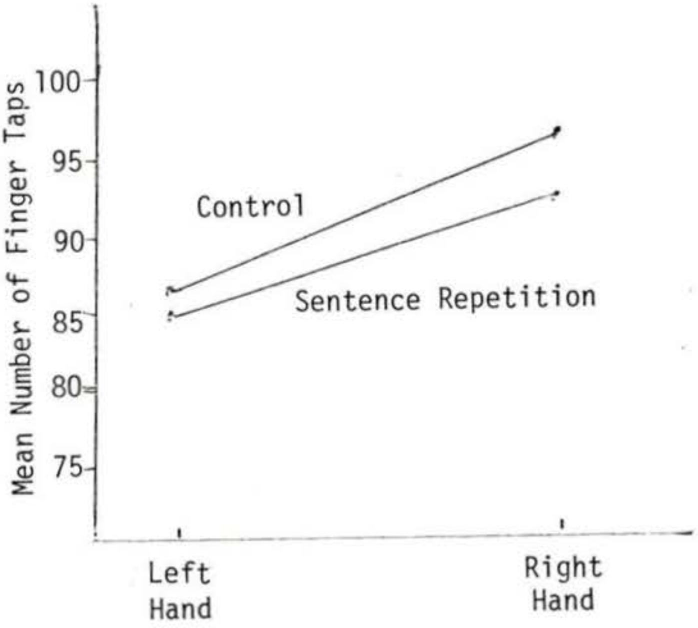

Figure 3: Mean number of finger taps for Right and Left hands during Control and Sentence Repetition conditions.

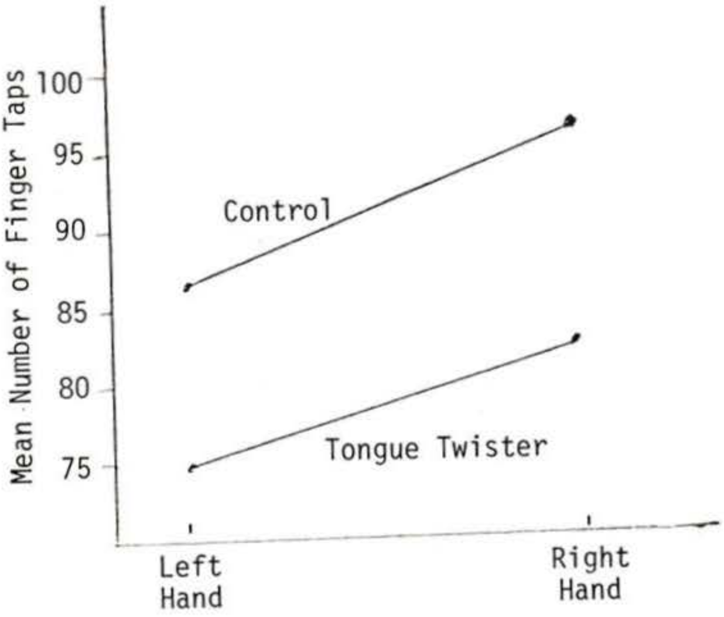

Figure 4: Mean number of finger taps for Right and Left hands during Control and Tongue Twister conditions.

Table 8: Summary Analysis of Variance on Raw Tapping Scores for Factors: Task, Hand, and Order

Source	df	MS	F[1]	p
Between Subjects				
Order	5	399.94		
Error term	42	1222.80		
Within Subjects[2]				
Task	3	3011.89	59.84	**
Task x Order	15	130.30	2.59	*
Error term	126	50.33		
Hand	1	6616.76	73.92	**
Hand x Order	5	102.02	1.14	
Error term	42	89.51		
Task x Hand	3	33.43	1.44	
Task x Hand x Order	15	14.32		
Error term	126	23.27		
TOTAL	383	221.47		

*$p < .02$
**$p < .001$

[1] F values less than 1 not shown

[2] All within subjects effects p values determined using degrees of freedom multiplied by the factor $\varepsilon = .614$ (Greenhouse & Geisser, 1959).

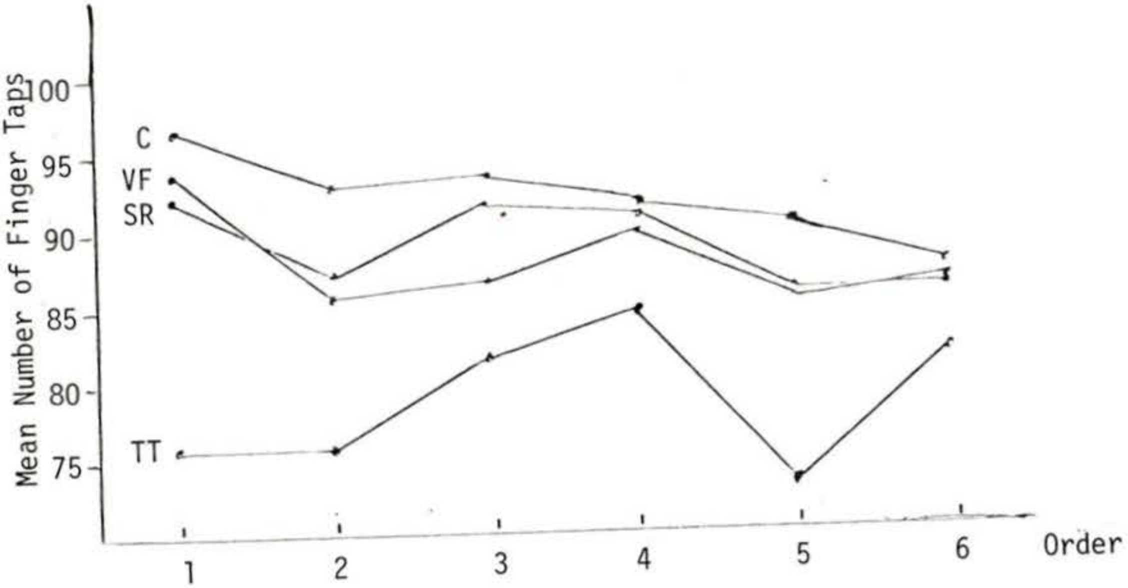

Figure 5: Mean number of finger taps by Order condition and Task.

Percentage Change from Baseline Scores

The raw tapping scores on the three concurrent tasks were converted into percentage change from baseline scores for each subject. Overall, there was a significant difference in the degree of interference associated with each of the three concurrent tasks (F = 47.12, $p < .001$). The greatest interference occurred for the TT condition (M = -14.30%). Considerably less interference resulted from the VF condition (M = -4.19%) and the SR condition (M = -3.14%). For each concurrent task condition, the percentage change from baseline scores were analyzed in a Hand (R, L) x Age (young, old) analysis of variance with Hand as a within subjects factor and Age as a between subjects factor. An overview of the percentage change from baseline data for each concurrent task is presented in Table 9, and analysis of variance results for each of the concurrent tasks appear in Tables 10, 11 and 12.

For the TT task there were no significant effects with regard to percentage change from baseline scores. There was an Age effect ($p < .025$) on the VF task in which older subjects showed greater decline from baseline (M = -6.45%) than young subjects (M = -1.75%). The SR task was associated with a similar Age effect ($p < .08$) as older subjects had greater decrement from baseline (M = -4.64%) than young subjects (M = -1.65%). There was also a significant Hand effect ($p < .003$) on the SR task in which greater decline from baseline occurred on the right hand (M = -4.56%) than the left hand (M = -1.73%). The significant effects of Age (VF and SR tasks) and Hand (SR task) are portrayed in Figures 6, 7 and 8. There were no significant interactions of Age x Hand.

Table 9: Means of Individual Percentage Change from Baseline Scores by Task, Hand, and Age

Task	Hand	Age	
		Young	Old
TT	R	-12.36%	-17.55%
	L	-11.20%	-16.09%
VF	R	- 3.28%	- 5.73%
	L	- .23%	- 7.18%
SR	R	- 2.80%	-6.32%
	L	- .49%	- 2.96%

Table 10: Summary Analysis of Variance on Percentage Change from Baseline Scores for Factors: Hand and Age for the Tongue Twister (TT) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Age	1	610.39	2.38	NS
Error term	46	256.67		
Within Subjects				
Hand	1	41.23		NS
Hand x Age	1	.54		NS
Error term	46	52.10		
TOTAL	95	156.37		

[1] F values less than 1 not shown

Table 11: Summary Analysis of Variance on Percentage Change from Baseline Scores for Factors: Hand and Age for the Verbal Fluency (VF) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Age	1	530.07	5.78	*
Error term	46	91.68		
Within Subjects				
Hand	1	15.28		
Hand x Age	1	121.41	2.37	
Error term	46	51.33		
TOTAL	95	76.27		

*p < .025

[1] F values less than 1 not shown

Table 12: Summary Analysis of Variance on Percentage Change from Baseline Scores for Factors: Hand and Age for the Sentence Repetition (SR) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Age	1	215.19	3.27	*
Error term	46	65.84		
Within Subjects				
Hand	1	193.15	9.97	**
Hand x Age	1	6.62		
Error term	46	19.37		
TOTAL	95	45.63		

*p < .08
**p < .003

[1] F values less than 1 not shown

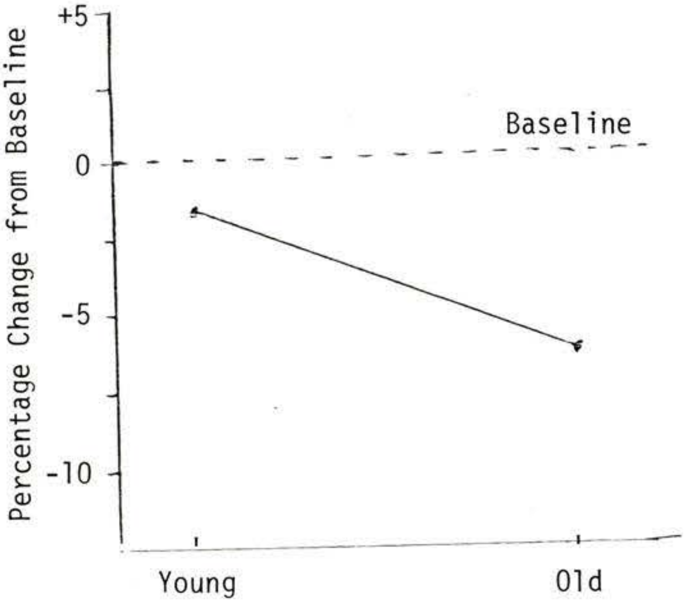

Figure 6: Mean individual percentage change from baseline for the Verbal Fluency concurrent task condition: young vs. older subjects

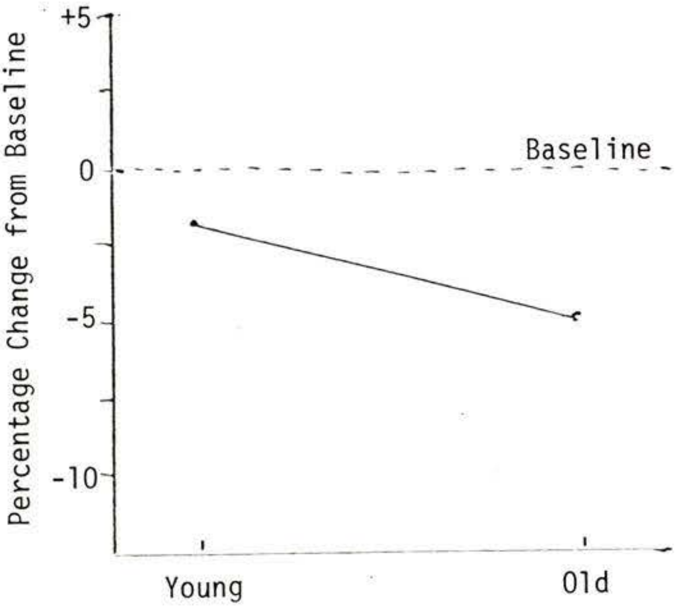

Figure 7: Mean individual percentage change from baseline for the Sentence Repetition concurrent task condition: young vs. older subjects.

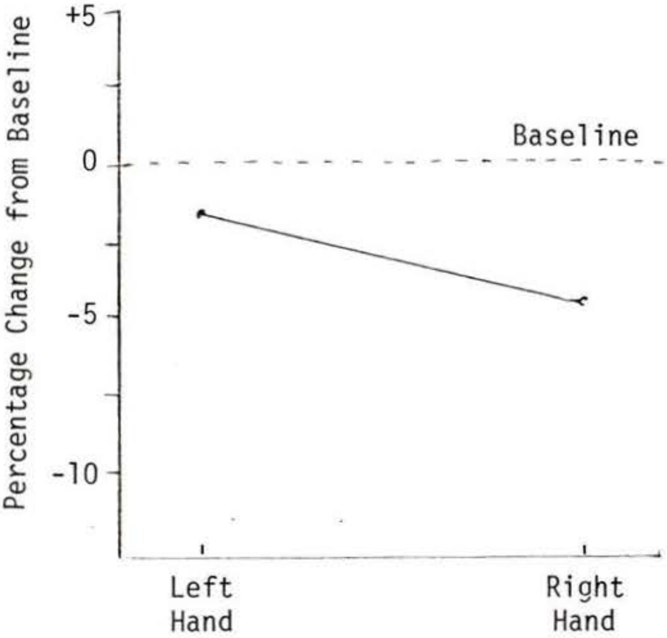

Figure 8: Mean individual percentage change from baseline for the Sentence Repetition concurrent task condition: right vs. left hand.

Difference Scores

Another instructive approach to understanding the results is to analyze the data in terms of difference scores: i.e., of right hand minus left hand raw tapping scores. This was done for each of the concurrent task conditions in a Task (C, TT or VF or SR) x Age (young, old) analysis of variance format. Since hand-related data were converted into one score per subject (R—L tapping) the Hand factor dropped out. An overview of the results is shown in Table 13 and the analyses of variance are summarized in Tables 14, 15, and 16.

The means presented in Table 13 reveal a tendency of a smaller tapping differnce between hands for the concurrent task conditions compared to control. The difference was significant for the SR task ($p < .002$), where the mean hand difference was 9.85 taps for Control compared to 7.17 for the SR concurrent task condition. There was a similar pattern for the TT task ($p < .08$), where the mean hand difference was 7.46 for the TT concurrent task condition. For the VF task there was the same pattern for young subjects but not for older subjects, although the interaction was not statistically significant.

Performance on Concurrent Verbal Tasks

Data were obtained on performance of the cognitive tasks concurrent to tapping. The means and standard deviations for these tasks are presented in Table 17. Cognitive performance was not significantly affected by age or tapping hand with the exception of an age difference on the SR task. Older subjects repeated fewer correct sentences than

Table 13: Means of Raw Tapping Difference Scores (Right Hand—Left Hand) by Task and Age*

Task	Age	
	Young	Old
C	9.71	10.00
TT	7.25	7.67
VF	6.21	10.96
SR	7.42	6.92

*Smaller numbers reflect less difference between hands.

Table 14: Summary Analysis of Variance on Raw Tapping Difference Scores (Right Hand—Left Hand) for Factors: Task and Age for the Tongue Twister (TT) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Age	1	3.01		
Error term	46	138.02		
Within Subjects				
Task	1	137.76	3.25	*
Task x Age	1	.09		
Error term	46	42.38		
TOTAL	95	88.84		

*$p < .08$

[1] F values less than 1 not shown

Table 15: Summary Analysis of Variance on Raw Tapping Difference Scores (Right Hand—Left Hand) for Factors: Task and Age for the Verbal Fluency (VF) Concurrent Task Condition

Source	df	MS	F^1	p
Between Subjects				
Age	1	152.51	1.55	NS
Error term	46	98.23		
Within Subjects				
Task	1	38.76		NS
Task x Age	1	119.26	2.25	
Error term	46	52.95		
TOTAL	95	76.47		

[1] F values less than 1 not shown

Table 16: Summary Analysis of Variance on Raw Tapping Difference Scores (Right Hand—Left Hand) for Factors: Task and Age for the Sentence Repetition (SR) Concurrent Task Condition

Source	df	MS	F^1	p
Between Subjects				
Age	1	.26		
Error term	46	124.31		
Within Subjects				
Task	1	173.34	10.95	*
Task x Age	1	3.76		
Error term	46	15.83		
TOTAL	95	69.73		

*$p < .002$

[1] F values less than 1 not shown

Table 17: Means and Standard Deviations of Cognitive Task Performance by Tapping Hand and Age*

Task	Hand	Age	
		Young	Old
TT[1]	R	4.33 (1.34)	4.58 (2.17)
	L	4.46 (1.44)	4.92 (2.50)
VF[2]	R	7.21 (2.08)	6.96 (3.25)
	L	6.71 (2.24)	6.67 (2.93)
SR[3]	R	4.75 (0.53)	3.79 (0.78)
	L	4.88 (0.45)	3.88 (0.74)

[1] Number of tongue twisters uttered correctly.

[2] Number of proper words uttered.

[3] Number of sentences repeated correctly.

*Standard deviations are in parentheses.

did young subjects during the concurrent SR-tapping condition ($t = 6.10$, $p. < .001$).

Discussion

There were several findings that were consistent for each task condition. Right hand tapping scores were higher than left hand tapping scores, which is not surprising in a sample of right handed subjects. Younger subjects tapped faster than older subjects in all task conditions. This also was not an unexpected finding since age decline in speed-related motor performance has been well documented (e.g., Welford, 1958). Another consistent finding was that each concurrent task (TT, VF, SR) was associated with significantly low tapping scores relative to performance on the Control (single task tapping) trials. Each task resulted in interference with tapping performance, that is, there were general effects of divided attention. The crucial questions of interest are whether divided attention effects differed for hand, age, or for some combination of hand and age, and for which tasks. Several kinds of dependent measures were employed to answer these questions and generally the different measures reveal consistent patterns. In this section the patterns are summarized and related to the three hypotheses (see above).

Tongue Twister Concurrent Task Condition

The TT task was associated with the greatest degree of interference with tapping, as is clearly demonstrated in Tables 2 and 9. The difficulty involved in verbalizing the tongue twister phrases relative to uttering simple sentences (SR task) and self-generated words (VF task) probably accounts for the higher degree of interference. The data tend to be more variable for the TT condition (see Figure 5) as different effects were found for different orders. Although analyses of Order effects do not show a main effect of Order, an interaction of Order x Task did occur and, as Figure 5 portrays, the interaction seems to have been confined to the TT task. Fortunately, order-related effects should not present difficulty in interpretation of findings since orders were counterbalanced across subjects within each age group.

Hypothesis one (age differences in divided attention) was not supported for this task, as significant age differences in decrement from Control were not found on any of the dependent measures employed.

There was a trend towards support of hypothesis two (greater right hand than left hand decrement from baseline tapping performance). This trend approached statistical significance for the analyses of raw tapping data and difference scores. The smaller difference scores between hands for the TT condition, compared to Control difference scores, are probably a result of a combination of greater right hand decrement and less left hand decrement. However, the frequency data in Tables 1 and 2 suggests that a pattern of bilateral decline is fairly common. All in all, support for hypothesis two is moderate and only suggestive at this point. Hypothesis three (age differences in patterns of asymmetrical decrement) received no support.

Verbal Fluency Concurrent Task Condition

Analyses of raw tapping data and percentage change from baseline scores both support hypothesis one, as older subjects showed greater decrement from baseline tapping than did younger subjects (see Figures 2 and 6). All the measures suggest support for hypothesis two with regard to the young subjects (more right hand decrement) but the pattern does not hold for older subjects. An interaction such that asymmetrical decrement is different with age (hypothesis three) is suggested by observing the means in Table 9 but the pattern does not approach statistical significance.

Sentence Repetition Concurrent Task Condition

There were trends toward support of hypothesis one, as older subjects showed somewhat greater percentage decline from baseline than did young subjects. Cognitive performance was also affected such that older subjects uttered fewer correct sentences than young subjects. This finding may be an artifact of stimuli presentation modality, as the SR task was presented auditorally while the TT and VF task stimuli were visually presented. Natural age-related hearing deficits could account for the age difference in sentence repetition scores. All the measures converge on clear support for hypothesis two in which greater right than left hand decrement is the consistent finding. There is no supportive evidence for hypothesis three.

In summary, all three concurrent tasks (TT, VF, SR) were associated with interference on finger tapping. This general effect of divided attention was especially evident with the TT task. Hypothesis one (age differences in divided attention) was supported by the VF task and a trend was discernible on the SR task. As for hypothesis two (intrahemispheric competition) there was substantial support from data on the SR task, some supportive evidence regarding young subjects on the VF tasks, and a trend towards significance on the TT task. The fact that this hypothesis receives support from tapping data but little support from performance on the concurrent tasks, is consistent with previous studies (e.g., Bowers, Heilman, Satz, & Altman, 1978). The third hypothesis (age differences in intrahemispheric competition) received very little support. In the next chapter, the three hypotheses will be explored further via post hoc analyses in which only highly lateralized subjects (on the basis of Control tapping scores) are included in the analyses. The effects of tapping practice are also examined.

CHAPTER 4

SUPPLEMENTARY ANALYSES

Tapping Practice

In this study counterbalancing of hand and task orders was employed in order to distribute any practice or fatigue effects equally across the experimental conditions. This avoids problems of interpretation in the event that practice or fatigue effects do occur for conditions in which order has not been varied. Although counterbalancing avoided such difficulties in the present experiment it is nevertheless instructive to examine whether practice effects or fatigue effects occurred, and if these effects were different on the basis of hand, task, or age.

Data on raw tapping control scores were analyzed. There were four control trials (tapping only) for each hand and the trials were spaced at equal intervals throughout the experiment. The scores were analyzed in a Time (1, 2, 3, 4) x Hand (R, L) x Age (young, old) analysis of variance with Age as a between subjects factor and Time and Hand as within subjects factors. A summary of the analysis of variance results is presented in Table 18.

There were main effects of Age, Hand, and Time and no interactions occurred. Young subjects tapped faster than older subjects and both age groups tapped faster with the right hand. Tapping scores improved across time. The practice effects are depicted in Figures 9 and 10 with regard to the Hand and Age factors, respectively.

Table 18: Summary Analysis of Variance on Raw Tapping Control Scores for Factors: Time, Hand, and Age

Source	df	MS	F[1]	p
Between Subjects				
Age	1	7839.13	11.29	**
Error term	46	694.53		
Within Subjects[2]				
Hand	1	8372.00	47.91	**
Hand x Age	1	18.82		
Error term	46	174.75		
Time	3	161.43	8.27	*
Time x Age	3	20.76	1.06	
Error term	138	19.54		
Hand x Time	3	15.02	1.12	
Hand x Time x Age	3	6.72		
Error term	138	13.38		
TOTAL	383	160.24		

*$p < .007$
**$p < .001$

[1] F values less than 1 not shown.

[2] All within subjects effects p values determined using degrees of freedom multiplied by the factor $\varepsilon = .307$ (Greenhouse & Geisser, 1959).

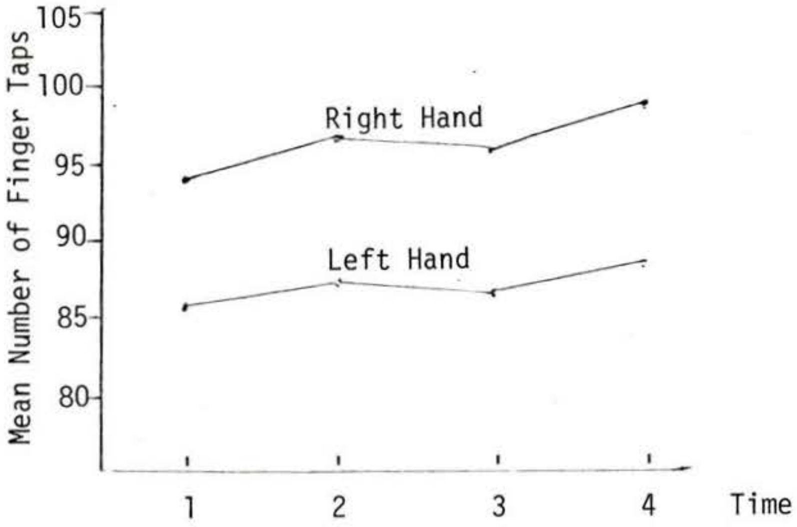

Figure 9: Mean number of finger taps by Time and Hand.

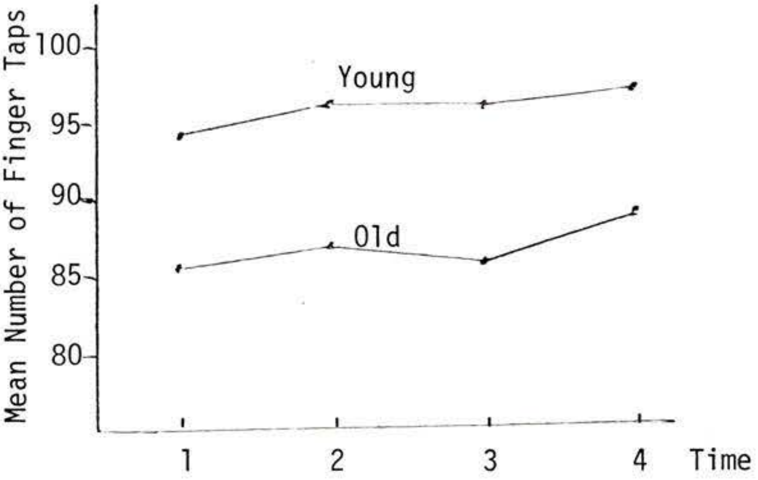

Figure 10: Mean number of finger taps by Time and Age.

Post Hoc Analyses on Subjects with Highly Lateralized Control Tapping Performance

Post hoc analyses were carried out to explore the results for well-lateralized subjects only. A laterality criterion based on the control tapping trials was arbitrarily established by this investigator. The criterion was that the mean of the four control tapping trials with the right hand must be at least two standard deviations (SDs) greater than the mean of the four control tapping trials with the left hand (based on the larger SD).

Of the 48 subjects, 29 met this laterality criterion with 17 of the 24 young subjects and 12 of the 24 older subjects comprising the group. Data on the 29 subjects who met the criterion were analyzed by percentage change from baseline scores and right minus left tapping difference scores. Frequency data are presented to provide an overview of the results

Overview

In Tables 1, 2, and 3 frequency data were provided to present an overview of the results for all subjects. In this section comparable tables are presented for highly lateralized subjects in particular (see Tables 19, 20, and 21).

Table 19, based on a greater than 1% difference between hands on percentage change from baseline scores, reveals a pattern of greater right than left hand decrement under concurrent task conditions. The differences are statistically significant for the VF condition

Table 19: Number of Subjects with Patterns of Asymmetric Tapping Change on Concurrent Tasks for Percentage Change from Baseline Scores for Highly Lateralized Subjects

Task	Percentage Change from Baseline		
	Greater R than L Decrement (or more L enhancement)	Greater L than R Decrement (or more R enhancement)	Less than 1% Difference Between Hands
TT	16	9	4
VF	19	6	4
SR	22	4	3

R = right hand
L = left hand

Table 20: Number of Subjects with Bilateral, Unilateral, or No Tapping Decrement on Concurrent Tasks for Highly Lateralized Subjects*

Task	Decrement from Baseline*			
	Bilateral (R & L)	Unilateral		No Decrement
		R only	L only	
TT	16	6	5	2
VF	4	9	2	14
SR	4	6	1	18

R = right hand
L = left hand

*Decrement based on criterion of at least 2 SDs from control score for the given hand.

Table 21: Number of Subjects with Bilateral or Unilateral Tapping Enhancement on Concurrent Tasks, for Highly Lateralized Subjects*

Task	Enhancement from Baseline*		
	Bilateral	Unilateral	
		R only	L only
TT	0	0	2
VF	0	1	5
SR	0	1	3
Total Across Tasks	0	2	10

R = right hand
L = left hand

*Enhancement based on criterion of at least 2 SDs from control score for the given hand.

($chi^2 = 6.76$, $p < .01$) and for the SR condition ($chi^2 = 12.46$, $p < .001$). In Table 20, involving a criterion of at least two SDs separation of the concurrent tapping score from the person's control score, there is a similar pattern of greater right than left decrement from control except for bilateral decline in the TT condition. Table 20 also reveals the high interference of the TT task (greatest bilateral decrement and least instances of no decrement) relative to the other two concurrent tasks. The VF and SR tasks appear to have produced a similar degree of interference, with the SR task resulting in the most frequent instances of no substantial decrement from control performance. Finally, Table 21 indicates a greater incidence of left hand enhancement across the concurrent task conditions which complements findings of more frequent right hand decrement.

Percentage Change from Baseline Scores

The data were analyzed in a one-factor (Hand) within subjects analysis of variance. The means for the percentage change from baseline scores for the 29 highly lateralized subjects are presented in Table 22, and analysis of variance results for each concurrent task condition are shown in Tables 23, 24, and 25. The pattern is of greater right than left hand decline from baseline for each concurrent task condition. Differences are significant for the VF task ($p < .02$) and the SR task ($p < .001$). The findings are graphically depicted in Figure 11.

Further analyses were done to compare results for subjects who "passed" the laterality criterion versus subjects who "failed" the criterion. In order to do this 10 subjects were excluded from the "Passed" (highly lateralized) group of 29 since the "Failed" (less lateralized) group consisted of only 19 subjects. While equal numbers of older subjects comprised the Passed and Failed groups (12 per group) there were 17 young subjects in the Passed group and only 7 in the Failed group. Therefore 10 subjects were randomly excluded from the young subjects in the Passed group to create equal sample sizes (n's) with similar age composition. Thus, two groups of equal size ($n = 19$ per group) were created for the purpose of comparing data of Passed versus Failed subjects in regard to the laterality criterion.

The data for the two groups (38 subjects in all) were analyzed in a Laterality Criterion (Passed, Failed) x Hand (Right, Left) analysis of variance format with Hand as a within subjects factor. Means of

Table 22: Means of Percentage Change from Baseline Scores by Task and Hand, for Highly Lateralized Subjects

Task	Hand	Means
TT	R	-13.60
	L	-10.97
VF	R	- 4.61
	L	- .37
SR	R	- 3.83
	L	+ .75

R = right hand
L = left hand

Table 23: Summary Analysis of Variance of Percentage Change from Baseline Scores for the Tongue Twister (TT) Concurrent Task Condition, for Highly Lateralized Subjects

Source	df	MS	F	p
Between Subjects				
Error term	28	192.37		
Within Subjects				
Hand	1	100.32	2.20	NS
Error term	28	45.67		
TOTAL	57	118.69		

Table 24: Summary Analysis of Variance of Percentage Change from Baseline Scores for the Verbal Fluency (VF) Concurrent Task Condition, for Highly Lateralized Subjects

Source	df	MS	F	p
Between Subjects				
Error term	28	53.27		
Within Subjects				
Hand	1	260.80	6.41	*
Error term	28	40.67		
TOTAL	57	50.72		

*p < .02

Table 25: Summary Analysis of Variance of Percentage Change from Baseline Scores for the Sentence Repetition (SR) Concurrent Task Condition, for Highly Lateralized Subjects

Source	df	MS	F	p
Between Subjects				
Error term	28	40.80		
Within Subjects				
Hand	1	303.84	13.45	*
Error term	28	22.60		
TOTAL	57	36.47		

*p < .001

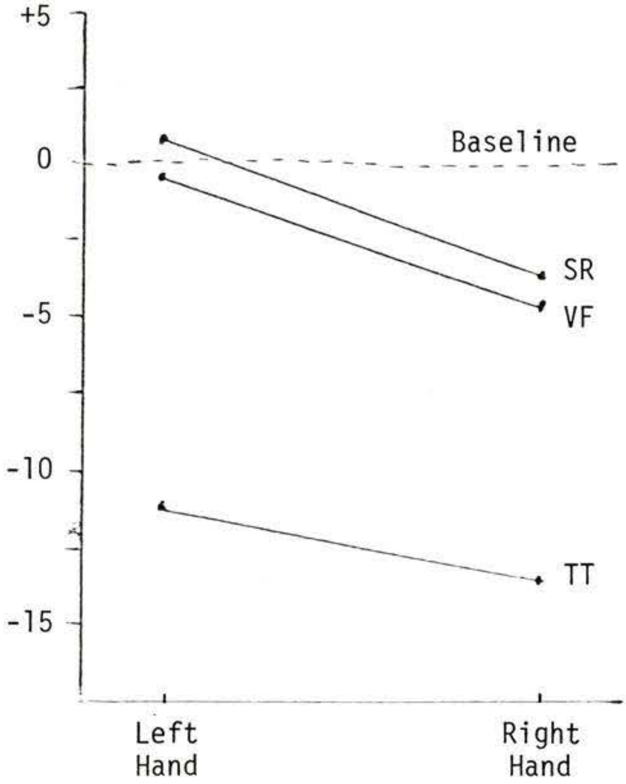

Figure 11: Mean individual percentage change from baseline for the concurrent task conditions (TT, VF, SR): right vs. left hand for highly lateralized subjects.

percentage change from baseline scores are presented in Table 26 while summaries of analysis of variance results for each concurrent task condition are shown in Tables 27, 28, and 29.

The means reveal a pattern of greater right than left hand decline from baseline tapping for Passed subjects but bilateral or greater left sided decrement for Failed subjects. This Laterality Criterion by Hand interaction effect was significant for the VF condition ($p < .003$) and for the SR condition ($p < .025$). These interactions are portrayed in Figures 12 and 13.

For the SR task there were also main effects of Laterality Criterion ($p < .05$) and Hand ($p < .02$). There was greater decrement from baseline for subjects who failed the criterion ($M = -5.59\%$) compared to subjects who passed the criterion ($M = -1.68\%$). The right hand was associated with greater decline from baseline ($M = -4.89\%$) than the left hand ($M = -2.38\%$).

Table 26: Means of Percentage Change from Baseline Scores by Laterality Criterion, Hand, and Concurrent Task Condition

Laterality Criterion	Hand	Concurrent Task Condition		
		TT	VF	SR
Passed (n = 19)	R	-14.50	-5.50	-4.10
	L	-12.18	.00	+ .74
Failed (n = 19)	R	-17.02	-4.33	-5.68
	L	-17.72	-8.79	-5.50

Table 27: Summary Analysis of Variance on Percentage Change from Baseline Scores for Factors: Laterality Criterion and Hand, for the Tongue Twister (TT) Concurrent Task Condition

Source	df	MS	F^1	p
Between Subjects				
Laterality Criterion	1	308.30		NS
Error term	36	309.47		
Within Subjects				
Hand	1	12.41		NS
Hand x Lat. Crit.	1	43.43		
Error term	36	58.70		
TOTAL	75	181.57		

[1] F values less than 1 not shown.

Table 28: Summary Analysis of Variance on Percentage Change from Baseline Scores for Factors: Laterality Criterion and Hand, for the Verbal Fluency (VF) Concurrent Task Condition

Source	df	MS	F[1]	p
Between Subjects				
Laterality Criterion	1	276.45	2.38	
Error term	36	116.35		
Within Subjects				
Hand	1	5.23		
Hand x Lat. Crit.	1	471.56	10.10	*
Error term	36	46.69		
TOTAL	75	88.30		

*p < .003

[1] F values less than 1 not shown

Table 29: Summary Analysis of Variance on Percentage Change from Baseline Stores for Factors: Laterality Criterion and Hand, for the Sentence Repetition (SR) Concurrent Task Condition

Source	df	MS	F	p
Between Subjects				
Laterality Criterion	1	291.33	4.16	*
Error term	36	70.11		
Within Subjects				
Hand	1	119.75	6.51	**
Hand x Lat. Crit.	1	103.20	5.61	**
Error term	36	18.39		
TOTAL	75	49.34		

*p < .05
**p < .025

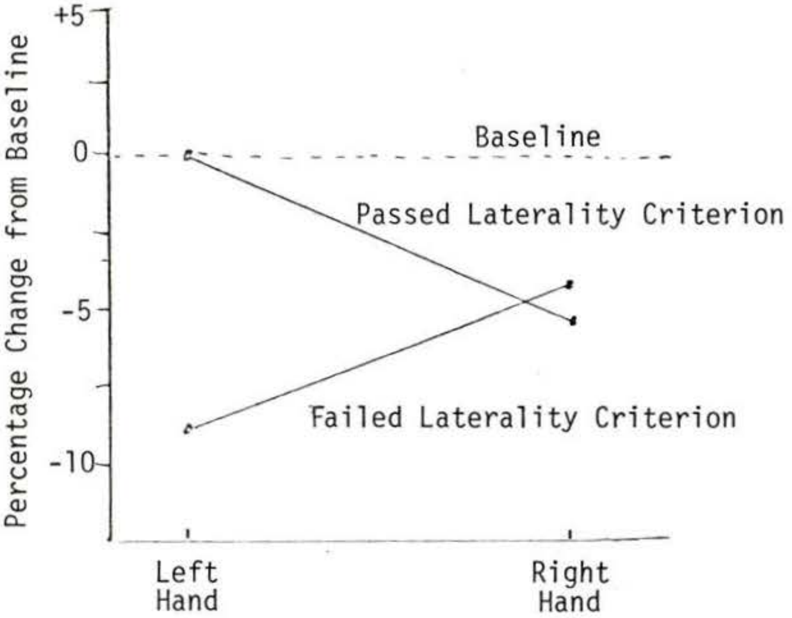

Figure 12: Mean individual percentage change from baseline for the Verbal Fluency concurrent task condition by Hand and Laterality Criterion.

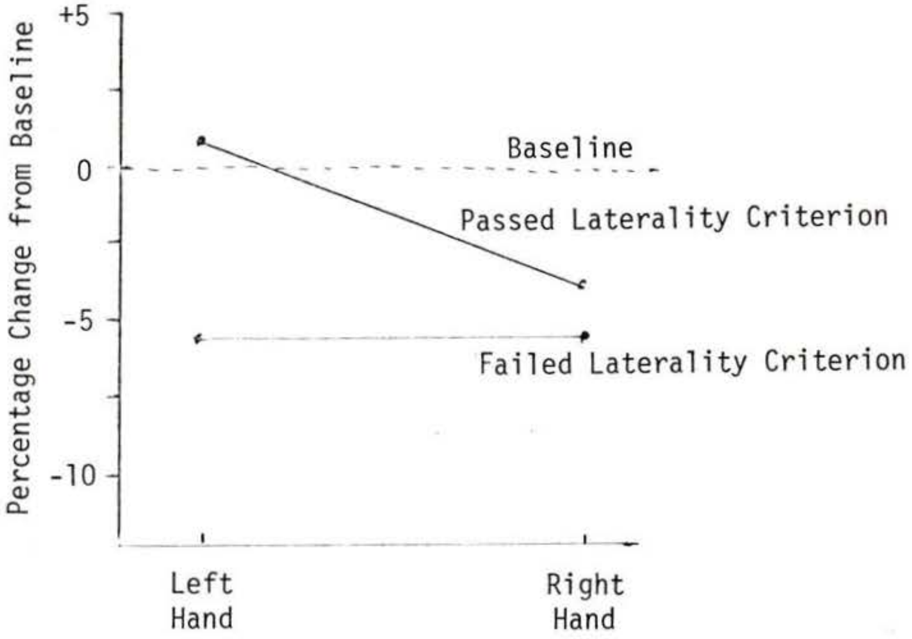

Figure 13: Mean individual percentage change from baseline for the Sentence Repetition concurrent task condition by Hand and Laterality Criterion.

Difference Scores

Difference scores (right hand minus left hand raw tapping scores) were analyzed in a one-factor (Task) within subjects analysis of variance for each concurrent task condition, in which Control difference scores were contrasted with difference scores on the given concurrent task. The means are shown in Table 30 and analysis of variance summaries appear in Tables 31, 32, and 33.

The means reveal a pattern of smaller difference scores for the concurrent task conditions relative to Control tapping. These differences are significant for each concurrent condition: TT ($p < .02$), VF ($p < .02$), and SR ($p < .001$). Concurrent task conditions, then, are associated with reduced differences between right and left tapping scores relative to trials where tapping is the only task.

Table 30: Means of Raw Tapping Difference Scores (Right Hand—Left Hand) by Task Condition, for Highly Lateralized Subjects*

Task	Difference Between Number of Right Minus Left Taps
C	14.28
TT	10.07
VF	9.45
SR	9.93

*Smaller numbers reflect less difference between hands.

Table 31: Summary Analysis of Variance on Raw Tapping Difference Scores (Right Hand—Left Hand) for Highly Lateralized Subjects: Control versus Tongue Twister (TT) Concurrent Task Condition

Source	df	MS	F	p
Between Subjects				
Error term	28	120.83		
Within Subjects				
Task	1	256.62	6.97	*
Error term	28	36.80		
TOTAL	57	81.93		

*p < .02

Table 32: Summary Analysis of Variance on Raw Tapping Difference Scores (Right Hand—Left Hand) for Highly Lateralized Subjects: Control versus Verbal Fluency (VF) Concurrent Task Condition

Source	df	MS	F	p
Between Subjects				
Error term	28	91.64		
Within Subjects				
Task	1	337.93	7.53	*
Error term	28	44.90		
TOTAL	57	73.00		

*p <.02

Table 33: Summary Analysis of Variance on Raw Tapping Difference Scores (Right Hand—Left Hand) for Highly Lateralized Subjects: Control versus Sentence Repetition (SR) Concurrent Task Condition

Source	df	MS	F	p
Between Subjects				
Error term	28	109.80		
Within Subjects				
Task	1	273.72	15.66	*
Error term	28	17.47		
TOTAL	57	67.32		

*p < .001

Discussion

Tapping Practice

The data on practice effects reveal several interesting findings. First, there was a significant practice effect such that tapping performance on the control trials improved with time, which emphasizes the importance of counterbalancing hand and task orders. Secondly, this improvement was similar for both hands. A third finding of particular significance was that there was not a Time by Age interaction. In other words, control tapping performance improved across time in a similar manner for young and older subjects. This result is important when one considers the abundant literature on fatigue effects with older subjects (e.g., Welford, 1958). It is possible that the standard inter-trial interval of 30 seconds allowed sufficient recovery time from fatigue, and that shorter intervals (e.g., 10 seconds) might have resulted in differential practice or fatigue effects.

Post Hoc Analyses on Subjects with Highly Lateralized Control Tapping Performance

The analyses done on the data for highly lateralized subjects supplement the general findings on tapping asymmetries. Percentage change from baseline scores revealed a pattern of greater right sided tapping decrement from baseline for the SR and VF task conditions, and relatively bilateral decrement in the TT condition. Difference scores resulted in smaller hand differences for each concurrent task condition relative to Control. These findings for both measures are consistent with the results for all subjects, except with regard to the VF condition. Whereas (1) a hand asymmetry of greater right handed decline and (2) less of a hand difference relative to Control hand differences did *not* occur for the entire group of 48 subjects, these differences were significant for the 29 highly lateralized subjects.

The analyses that contrasted the 19 remaining subjects with 19 of the 29 highly lateralized subjects revealed a significant interaction of Hand by Laterality Criterion for each task (percentage change from baseline data). Highly lateralized subjects tended to show greater right hand decrement while less lateralized subjects had bilateral or greater left hand decline. The implication is that a criterion of laterality based on control tapping performance (and not just handedness questionnaires) may be a critical variable in enhancing the clarity of findings in experiments on intrahemispheric competition. A case in point is the fact that the VF concurrent task condition resulted in significantly greater right than left hand decrement from control for the highly lateralized subjects, but a significant asymmetry did *not* occur when all 48 subjects were in the analysis. Overall, the aforementioned post hoc analyses lend further support for hypothesis two (greater right than left hand decline from baseline tapping), especially for the VF concurrent task condition. The post hoc analyses did not address the issue of age differences.

CHAPTER 5

FINAL DISCUSSION AND CONCLUSIONS

Summary of Findings

Pilot experiments and a primary experiment were conducted to investigate adult age differences in divided attention and intrahemispheric competition. There were three hypotheses of particular interest: (1) that greater tapping decrements occur for older persons than for younger adults, regardless of hand; (2) that concurrent verbal-finger tapping task conditions produce greater right than left hand tapping decrement from Control (tapping only); (3) that there are age differences in intrahemispheric competition such that older persons show greater functional asymmetry (greater right than left hand decrement) than younger subjects during concurrent task conditions. Data relevant to these hypotheses was assessed for each concurrent task condition: TT (Tongue Twister), VF (Verbal Fluency), and SR (Sentence Repetition). Order and practice effects were analyzed as well, and post hoc analyses were carried out with regard to lateralization of Control tapping performance.

With regard to the entire group of 48 subjects in the primary experiment tapping was better with the right hand than with the left, and tapping performance was poorer in each concurrent task condition (TT, VF, and SR) relative to Control (single task tapping) performance.

The TT task was associated with the greatest interference while the VF and SR tasks resulted in considerably less, but still significant interference.

Raw tapping scores revealed that young subjects tapped faster than older subjects. Percentage change from baseline scores were employed in order to provide reasonable tests of age-related differences, since these scores are based on tapping decrement relative to each individual's own baseline (Control) performance. Age differences were found in the VF condition and a trend appeared in the SR condition, with greater decline from baseline tapping occurring for older subjects than for young subjects. Age differences were not found in the TT condition. Cognitive performance on the SR task was better for young subjects while there were no age differences in cognitive task performance on the TT and VF tasks. In general, effects of divided attention upon tapping performance occurred for each concurrent task, and there is evidence of age differences in divided attention in the VF and SR concurrent task conditions. This latter finding lends support to hypothesis one.

Data on asymmetry of tapping performance decrement relative to baseline were analyzed in a variety of ways (frequency counts, raw tapping scores, percentage change from baseline, and difference scores). The different measures revealed similar findings. Significantly greater tapping decrement from baseline occurred with the right hand than with the left for the SR task. It is noteworthy that while the SR condition was associated with the least overall interference, it consistently resulted in the most powerful effects of asymmetrical decline from baseline (greater right than left tapping decline). A trend of greater right hand decrement was found in the TT condition but was not statistically significant. A similar pattern was apparent in the VF condition for young subjects but not for all subjects combined. There were no significant differences between young and older subjects with regard to degree of asymmetric change from baseline tapping performance. The findings lend support to hypothesis two (especially for the SR condition) and do not provide support for hypothesis three.

An arbitrarily established "laterality criterion" was the focus of post hoc analyses aimed at differentiating subjects who showed the asymmetrical (greater right than left) decrement phenomenon from those who did not reveal that pattern. The criterion (at least two standard deviations separating higher right from left individual Control tapping scores, based on the larger standard deviation) was successful in discriminating among subjects for the VF and SR tasks. Subjects who met the laterality critierion showed greater right than left hand decline from baseline, while those who did not meet the criterion had bilateral or even more left than right hand decrement. This Hand by Laterality Criterion interaction was significant for the VF and SR conditions but not for the TT condition.

In addition to contrasting subjects who met the laterality criterion with those who did not meet it, data were analyzed for the 29 highly lateralized subjects only. The frequency, percentage change from baseline, and difference score data were similar to the findings for all 48 subjects, with two notable exceptions: (1) significant asymmetrical decline from baseline (greater right than left hand decline) occurred for the VF condition whereas this pattern was not significant for all subjects combined; (2) difference scores were significantly smaller in each concurrent task condition relative to Control, whereas for all subjects combined the effect did not occur for the VF condition. The results for highly lateralized subjects, then, add further support to hypothesis two, particularly for the VF condition.

An analysis of order effects (six combinations of hand and task orders within each age group) revealed an Order by Task effect but no main effect of Order and no effect of Order by Hand. The Order by Task interaction occurred primarily in the TT condition where tapping interference and variability of scores were highest. In any case the finding does not confound interpretation of results since orders were counterbalanced.

Practice effects were assessed by examining performance on the four Control tapping trials which were spaced at equal intervals across the experiment. Subjects' tapping scores became higher with time, and improvement was similar for both hands and both age groups (no interactions).

Overall, the findings provide support for hypothesis one (age differences in divided attention) and hypothesis two (asymmetric, right hand decline from baseline), but not necessarily for each task. There was no support for hypothesis three (age differences in asymmetric decline from baseline). These conclusions are based on similar results of several different measures. Explanations for the findings are discussed in the following sections.

Divided Attention

The interference of each concurrent task with tapping performance is consistent with well documented research findings of divided attention effects (e.g., Welford, 1968). Divided attention effects usually are explained in terms of pooled capacity models of information processing (e.g., Broadbent, 1971; Kahneman, 1973) which predict decrements in performance when task demands exceed the available information processing capacity. It is plausible that the VF and TT tasks represent increasing levels of difficulty, and that the increasing load of these cognitive tasks (especially TT) exceed the available processing capacity in the concurrent task conditions which resulted in corresponding decrement on finger tapping.

Models of information processing are not explicit as to why there might be age differences in divided attention. Although one may be tempted to conclude that older persons have less processing capacity than younger adults this may not necessarily be the case. Craik (1973) has suggested that the portion of available processing that is required for organizing the division of attention is greater for older persons. This does not necessarily imply that older persons have less processing capacity. It may be that of the available capacity which perhaps is the same for young and older persons, the older person must allocate more towards the division of attention. When a concurrent task required a high portion of processing capacity divided attention effects may result for all subjects regardless of age. Indeed, age differences in divided attention occurred for the less demanding SR and VF conditions but not for the much greater demanding TT condition.

It is clear, then, that there are age related deficits in divided attention for moderate levels of concurrent task difficulty. It is not clear whether these age differences are a function of less overall information processing capacity for older persons, whether a greater portion of available capacity must be allocated by older persons for organizing the division of attention, or both.

Intrahemispheric Competition

The findings of asymmetrical decline from baseline tapping performance (greater right than left hand decrement) are consistent with the intrahemispheric competition hypothesis and the more general functional cerebral distance model. Right hand tapping presumably resulted in greater overlap in "functional space" than left hand tapping, since closely connected control centres in the left cerebral hemisphere probably were involved both for right tapping and verbal task performance. Left hand tapping (right hemisphere mediated) perhaps resulted in less overlap in functional space with verbal task performance (left hemisphere mediated). Kinsbourne's functional distance model predicts that with "correlated" tasks (the same superordinate routine programmed concurrently by different parts of the brain), performance is minimized if the loci of programming are far away since the concurrent task will require additional programming. On the other hand, "uncorrelated" concurrent tasks (such as the ones employed in the present experiment) are predicted to lead to poorest performance when the loci of programming are close together (e.g., in the same hemisphere). This is due to vigorous competition of the two patterns of brain activation which necessitates massive interpolated inhibition to counteract the competition. Performance is maximized if the loci of programming for the uncorrelated tasks are far removed. In that case only a minor inhibitory barrier between the concurrent task programs is required to reduce interfering "cross-talk."

It is a moot issue as to whether verbal processing or, more specifically, motor aspects of speech production are really the cause of asymmetrical tapping decline. Although there is suggestive evidence that speech production per se does not account for the findings (see Bowers et al., 1978), either result does not really affect the functional distance model. It is the distance between loci of programming and whether the concurrent tasks are correlated that relate to the functional distance model.

Findings of asymmetric performance occurred only for the motor (finger tapping) task and not for any of the concurrent cognitive tasks. This is not an atypical result (e.g., Bowers et al., 1978; Hiscock & Kinsbourne, 1980). This pattern of motor but not cognitive-verbal task asymmetry has been referred to by Bowers et al. as the "one-way street phenomenon" (1978, p. 555) which cannot be predicted within the framework of Kinsbourne's model. There are several possible explanations for this phenomenon. Bowers et al. suggest that there may be a hierarchical arrangement such that higher order cognitive systems interfere with lower order motor systems but not vice versa. It is necessary to include motor tasks of varying difficulty to test this explanation. A second possibility, suggested by Hicks and Kinsbourne (1980), is that asymmetry does not result because there is only a small magnitude of general interference on verbal performance. The results of the present experiment argue against this explanation since the least interfering of the three verbal tasks (SR) consistently was associated with the most powerful asymmetry effects. A third possibility, suggested by the present author, is that only a small range of scores is possible on the verbal tasks while a relatively much larger range of scores is possible on the motor task. Perhaps narrower ranges of task performance mitigate against finding both general and asymmetric interference.

It is especially interesting that no age differences in intrahemispheric competition were found, regardless of which concurrent task was employed. This is consistent with Kinsbourne's "developmental invariance" hypothesis of language lateralization and related findings of no differences in asymmetric decline between young children and older children (Hicks & Kinsbourne, 1980). It appears, then, that concurrent task performance differences between young adult and older adult persons are due to general effects of divided attention with no special deficit resulting from intrahemispheric competition.

Differences with Regard to the Laterality Criterion

More powerful asymmetry effects were found in the VF condition for subjects who met the laterality criterion based on Control tapping performance. Comparisons between highly lateralized subjects and those who did not meet the criterion revealed greater right hand decline for lateralized subjects in each concurrent task condition. Findings of greater bilateral and left sided decrement for less lateralized subjects are consistent with results for left handed subjects (e.g., Hicks, 1975). Since the speech lateralization of left-handers tends to be more varied and less complete than that of right-handers (Rasmussen & Milner, 1975), greater right hand decrement may not occur as it does for right handed subjects. Likewise, the 19 subjects in the present experiment who did not meet the laterality criterion may represent a group of persons with more varied and less complete speech lateralization relative to subjects who met the criterion, even though all the subjects were right-handers. What this suggests is that handedness questionnaires may not be the most effective method of selecting well-lateralized subjects for experiments on intrahemispheric competition. Experimental power can be furthered by employing a laterality criterion based on single task tapping performance.

Concluding Remarks

Overall, the research findings relevant to the three hypotheses are fairly clear. Age differences were found in divided attention for two of the three concurrent task conditions (support for hypothesis one). A pattern of greater right than left hand decrement from baseline was found for each concurrent task (support for hypothesis two), although findings for the TT condition usually approached but did not reach statistical significance. Age differences in asymmetric tapping decrement did not occur in any concurrent task condition (consistent lack of support for hypothesis three). The remaining comments focus on suggestions for future research.

Composition of the subject sample should receive special attention in further research. The issue of sex differences in intrahemispheric competition has not been entirely resolved. In the present experiment an initial effort was made to explore intrahemispheric competition among older adults, but an age range of 65 to 83 years represents a very heterogeneous group. It would be useful, for example, to include equal groups of persons aged 65-69, 75-79, and 85-89. Another aspect of subject group composition involves speech lateralization. As mentioned earlier, a laterality criterion based on single task performance of the manual task may be more useful than a handedness questionnaire in reducing variance and hence increasing experimental power. Furthermore, use of such a criterion in experiments involving age and/or sex comparisons may be critical in avoiding confounding results. In the present study, for example, 71% of the young subjects met the laterality criterion while only 50% of the older subjects met it. Although not a statistically significant difference, this lateralization difference between young and older subjects could have led to a confounding of age comparisons, that is, a confusion of whether age differences are due to the process of normal aging or to differences in speech lateralization.

Varying the difficulty of both concurrent tasks in a systematic way is an area that needs considerable attention. This might shed light on the "one-way street phenomenon" where verbal performance is not disrupted as severely and asymmetrically as manual performance. It would be helpful to ascertain, for a given concurrent task combination, the minimal degree of interference necessary for asymmetric decrement and the maximal interference that can still result in asymmetric decline from baseline, that is, at what point similar bilateral decrement occurs for each hand. Perhaps task difficulty can be varied without altering the basic task.

Finally, the issue of age differences can be explored further. What are the effects if inter-trial intervals are shortened? What age differences might occur for nonverbal concurrent tasks? As is typical in experimental research, the present investigation has raised more questions than answers. It is hoped that, in addition to suggesting a few answers, this research will lead to an expanded breadth of research in the areas of intrahemispheric competition and cognitive changes with aging.

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APPENDIX A

TASK STIMULI

TONGUE TWISTERS (visual presentation)

Practice trial (without tapping):

Seals sliding silently ashore.

Experimental trials (concurrent with tapping):

Great gray geese grazing gaily.
Tim the thin twin tinsmith.

VERBAL FLUENCY (visual presentation)

Practice trial: T
Experimental trials: P; B

SENTENCE REPETITION (auditory presentation)

Practice trial:

Bring the table closer to me.
Summer is coming very late.
The water was too hot to touch.
The blue-birds were singing all day.
The paper was under the chair.
The sun was shinging throughout the day.
He entered about eight o'clock that night.

Experimental trials (trial 2 began with sentence after the last one completed in trial 1):

The pretty house on the mountain seemed empty.
She wrote the letter to her brother in college.
The lady followed the path down the hill.
The market was full of people buying fruit.
The island was first noticed by the young boy.
In the future he will finish work quite early.
The distance is too far to travel by car.
He listened to the teacher telling the story.
The man told us the directions to the building.
The fat king knew how to rule his country.
Yesterday he said he would be near the station.
The general came to the scene of the battle.
He looked at the report which lay on the table.
His interest in the problem increased again.

APPENDIX B

HANDEDNESS QUESTIONNAIRE

HANDEDNESS QUESTIONNAIRE

A.	Are you right-handed or left-handed?	Right—Left—Mixed
B.	Do you condiser yourself strongly or moderately right-handed (or left-handed)?	Strongly—Moderately
C. 1.	With which hand do you write?	Right—Left—Both
2.	With which hand to you use a scissors?	Right—Left—Both
3.	With which hand do you use a screwdriver?	Right—Left—Both
4.	With which hand do you throw a ball?	Right—Left—Both
5.	In baseball, do you bat right-handed or left-handed?	Right—Left—Both
6.	With which hand do you use a hammer?	Right—Left—Both
7.	With which hand do you use a needle in sewing?	Right—Left—Both
8.	With which hand do you usually carry books?	Right—Left—Both
9.	With which hand do you usually carry a suitcase?	Right—Left—Both
10.	With which hand do you hold the toothbrush when you brush your teeth?	Right—Left—Both

Father: Siblings:

Mother: Brother 1: Sister 1:

Brother 2: Sister 2:

Brother 3: Sister 3:

Brother 4: Sister 4:

Husband/Wife:

Children (6 yrs and over): Son 1: Daughter 1:

Son 2: Daughter 2:

Son 3: Daughter 3:

Son 4: Daughter 4:

APPENDIX C

TASK INSTRUCTIONS

General Introduction

In this experiment you will be asked to do a few simple tasks. After you become used to each task sometimes you will be asked to do two tasks at the same time. I am not really interested in whether you perform the tasks better than other people, but rather I am concerned with certain patterns of performance which I will discuss with you at the end of the experiment. In any case, do the best you can on these tasks. The experiment should take less than an hour. (Experimenter administers Handedness Questionnaire and asks about the state of health if an older subject.)

Sentence Repetition Task

After you hear me say "start" I am going to say some sentences, and after I finish each sentence I want you to repeat it out loud, word for word. It is important for you to say the sentences as quickly and accurately as you can. This trial and most of the following trials last about 20 seconds. Any questions? Okay. Let's begin.

Tongue Twister Task

Now I am going to ask you to repeat a tongue twister kind of phrase out loud as rapidly and as accurately as you can. I will hold a card in front of you and on this card is the phrase to be repeated. When you see this phrase begin repeating it out loud. After a few correct repetitions I will remove the card and you will continue to recite the phrase from memory. Remember that both accuracy and speed are important. You will begin just after I say "start." Any questions?

Verbal Fluency Task

I am going to present a letter of the alphabet and ask you to say as many words as you can think of that begin with that letter. Any English word is acceptable other than proper names (such as people and cities) and profanities. For example, if I said "D" you might say "dog, delight, daisy, dreadful," and so on. Also, it is not permissible to use derivatives, such as saying "love, lover, lovely," and so on. Any questions? Okay. You will begin just after I say "start."

Finger Tapping Task

Now I will introduce you to another task—finger tapping. In this task you tap with either your right or left index finger as rapidly and consistently as you can. You begin tapping when you hear me say "start." (Experimenter demonstrates proper tapping procedure.) We will begin with some short practice trials. Any questions? Okay. Begin with your (right/left) hand when I say "start."

Experimental Trials

The following trials all involve tapping for 20-second periods. Some of the trials require tapping only, but on other trials you will be asked to perform another task (one of the previous tasks to which you were introduced) at the same time as finger tapping. It is important to always tap as rapidly as possible while maintaining a constant rate. When performing another task at the same time as tapping, try to divide your attention equally between the two tasks. Remember that performance on both tasks is important. There will be a 30-second rest period between each trial.

APPENDIX D

RAW DATA

Raw Data: Control Tapping

No.	Age	Order Condition	Right Hand				Left Hand			
			1	2	3	4	1	2	3	4
Young Subjects										
1	17	1	94	99	104	105	87	94	97	96
2	16	2	96	96	98	95	91	92	94	87
3	16	3	89	93	97	98	90	98	95	90
4	16	4	94	97	84	101	91	87	74	79
5	16	5	89	98	94	94	82	85	82	84
6	17	6	100	96	101	105	93	90	93	92
7	15	1	101	105	99	106	92	89	90	89
8	17	2	106	104	103	111	93	96	96	97
9	18	3	91	91	91	95	79	80	84	83
10	17	4	82	84	89	90	83	95	87	86
11	17	5	97	96	98	101	79	74	80	79
12	17	6	86	83	89	82	78	76	82	76
13	16	1	90	94	97	99	85	86	83	88
14	17	2	93	90	95	94	94	93	92	91
15	17	3	105	109	108	111	94	96	104	103
16	17	4	92	92	90	93	81	85	81	83
17	20	5	110	111	111	111	97	94	84	90
18	28	6	106	111	111	111	98	95	97	98
19	29	1	108	118	109	112	94	95	98	107
20	27	2	117	117	117	117	111	108	106	112
21	29	3	106	111	112	110	102	103	99	100
22	18	4	96	100	96	102	92	92	89	91
23	19	5	103	117	119	110	94	90	97	98
24	22	6	113	121	119	112	90	107	103	98

—table continues—

Control Tapping, continues

No.	Age	Order Condition	Right Hand				Left Hand			
			1	2	3	4	1	2	3	4
Old Subjects										
1	70	1	90	94	93	95	78	85	87	85
2	73	2	76	80	78	81	73	77	75	76
3	65	3	103	106	107	105	67	74	65	64
4	67	4	134	140	142	137	109	98	87	99
5	69	5	94	98	101	101	87	87	88	84
6	69	6	93	91	88	98	78	77	74	79
7	77	1	107	112	103	114	90	98	103	94
8	76	2	81	87	87	87	74	78	77	67
9	72	3	90	91	95	97	81	86	82	95
10	76	4	96	98	90	97	72	70	70	73
11	75	5	95	84	81	86	74	73	73	80
12	69	6	98	95	79	86	75	71	68	75
13	69	1	105	105	104	112	96	94	93	96
14	76	2	99	98	98	96	88	92	91	93
15	69	3	94	94	98	99	89	93	91	96
16	65	4	76	94	89	88	69	75	80	78
17	67	5	85	80	86	88	76	80	84	81
18	75	6	72	74	72	74	73	74	75	75
19	69	1	87	96	87	88	98	92	82	88
20	82	2	77	94	86	97	90	83	88	89
21	75	3	75	79	88	92	82	80	87	99
22	83	4	94	90	81	92	77	87	86	94
23	69	5	78	77	75	88	81	78	78	89
24	78	6	68	65	68	65	69	66	69	68

Raw Data: Concurrent Task Tapping

No.	Age	Order Condition	Tongue Twisters		Verbal Fluency		Sentence Repetition	
			R-hand	L-hand	R-hand	L-hand	R-hand	L-hand
Young Subjects								
1	17	1	89	81	98	98	95	91
2	16	2	85	78	94	90	98	89
3	16	3	85	82	87	83	94	95
4	16	4	98	90	103	91	91	83
5	16	5	79	78	85	83	94	83
6	17	6	98	88	99	96	101	93
7	15	1	83	76	93	89	98	88
8	17	2	93	86	98	89	97	92
9	18	3	70	52	81	87	89	85
10	17	4	76	65	88	85	89	82
11	17	5	78	62	97	80	90	80
12	17	6	81	71	88	73	91	85
13	16	1	74	79	87	82	86	84
14	17	2	72	74	88	88	87	86
15	17	3	93	93	105	108	104	98
16	17	4	80	59	89	71	85	74
17	20	5	101	83	107	92	100	90
18	28	6	101	101	106	99	116	95
19	29	1	105	86	122	101	109	100
20	27	2	106	107	107	116	110	111
21	29	3	103	94	108	101	109	104
22	18	4	79	80	92	85	99	91
23	19	5	91	86	105	104	108	96
24	22	6	108	103	115	102	116	103

—table continues—

Concurrent Task Tapping, continues

No.	Age	Order Condition	Tongue Twisters		Verbal Fluency		Sentence Repetition	
			R-hand	L-hand	R-hand	L-hand	R-hand	L-hand
Old Subjects								
1	70	1	82	75	95	85	86	79
2	73	2	52	46	57	59	70	68
3	65	3	89	72	100	65	102	72
4	67	4	131	104	115	111	133	104
5	69	5	75	69	80	73	91	83
6	69	6	101	71	86	78	92	81
7	77	1	93	86	104	99	107	102
8	76	2	76	64	80	71	81	66
9	72	3	91	72	84	54	93	86
10	76	4	99	74	92	82	101	81
11	75	5	54	64	91	70	72	79
12	69	6	75	56	91	83	80	79
13	69	1	67	55	101	84	106	88
14	76	2	85	84	96	85	93	86
15	69	3	75	70	85	70	88	85
16	65	4	84	77	91	75	90	74
17	67	5	58	53	78	68	72	67
18	75	6	73	69	70	76	67	72
19	69	1	53	34	91	71	75	83
20	82	2	53	74	88	88	85	85
21	75	3	72	67	79	62	77	78
22	83	4	73	81	85	81	88	86
23	69	5	70	69	82	70	86	82
24	78	6	49	60	58	56	49	52

Raw Data: Verbal Task Performance

No.	Age	Order Condition	Tongue Twisters		Verbal Fluency		Sentence Repetition	
			R-hand	L-hand	R-hand	L-hand	R-hand	L-hand
Young Subjects								
1	17	1	3	3	5	6	5	5
2	16	2	5	5	6	7	5	4
3	16	3	5	5	9	4	5	5
4	16	4	3	3	5	6	4	5
5	16	5	3	6	8	8	5	5
6	17	6	6	3	8	6	5	5
7	15	1	6	5	3	4	5	5
8	17	2	3	5	9	5	5	5
9	18	3	4	3	5	6	5	5
10	17	4	3	2	9	10	4	5
11	17	5	2	6	5	4	4	5
12	17	6	8	5	9	8	5	5
13	16	1	4	8	7	9	5	5
14	17	2	3	2	7	7	4	5
15	17	3	6	6	9	8	6	6
16	17	4	4	4	9	6	4	4
17	20	5	4	4	10	6	5	4
18	28	6	4	5	10	9	5	5
19	29	1	4	4	8	6	5	5
20	27	2	4	3	4	1	4	4
21	29	3	5	4	6	10	5	5
22	18	4	5	6	7	9	5	5
23	19	5	5	5	5	6	5	5
24	22	6	5	5	10	10	4	5

—table continues—

Verbal Task Performance, continues

No.	Age	Order Condition	Tongue Twisters		Verbal Fluency		Sentence Repetition	
			R-hand	L-hand	R-hand	L-hand	R-hand	L-hand
Old Subjects								
1	70	1	3	5	5	8	5	5
2	73	2	3	6	9	4	4	4
3	65	3	3	7	7	4	5	5
4	67	4	10	8	15	14	5	5
5	69	5	4	7	6	7	4	4
6	69	6	5	3	6	3	4	5
7	77	1	5	4	6	6	4	4
8	76	2	3	4	3	4	4	4
9	72	3	7	13	9	7	4	4
10	76	4	6	6	11	13	4	3
11	75	5	4	5	5	6	2	3
12	69	6	6	4	5	5	3	4
13	69	1	4	4	5	6	4	4
14	76	2	10	7	7	11	2	4
15	69	3	4	6	12	9	4	4
16	65	4	3	2	8	7	4	4
17	67	5	4	3	3	6	4	4
18	75	6	4	4	2	5	4	4
19	69	1	5	4	5	3	4	4
20	82	2	5	5	10	10	4	2
21	75	3	5	5	11	4	3	3
22	83	4	0	0	5	5	3	3
23	69	5	4	3	9	7	4	4
24	78	6	3	3	3	6	3	3

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COMPETITION

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