8501113

Alpern, Carol Sober

INTERFERENCE AND ENTRAINMENT BETWEEN MANUAL AND LINGUISTIC ACTIVITIES

City University of New York PH.D. 1984

University
Microfilms
International 300 N. Zeeb Road, Ann Arbor, MI 48106

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark __√__.

1. Glossy photographs or pages ______
2. Colored illustrations, paper or print ______
3. Photographs with dark background __√__
4. Illustrations are poor copy ______
5. Pages with black marks, not original copy ______
6. Print shows through as there is text on both sides of page ______
7. Indistinct, broken or small print on several pages __√__
8. Print exceeds margin requirements ______
9. Tightly bound copy with print lost in spine ______
10. Computer printout pages with indistinct print __√__
11. Page(s) ____________ lacking when material received, and not available from school or author.
12. Page(s) ____________ seem to be missing in numbering only as text follows.
13. Two pages numbered ____________. Text follows.
14. Curling and wrinkled pages ______
15. Other ____

INTERFERENCE AND ENTRAINMENT BETWEEN
MANUAL AND LINGUISTIC ACTIVITIES

by

CAROL SOBER ALPERN

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1984

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

August 6th 1984
date

Michael Studdert-Kennedy
Chairman of Examining Committee

August 9, 1984
date

Irving Hochberg
Executive Officer

Arthur Boothroyd, Ph.D.

Margaret Lahey, Ph.D.

Edgar Zurif, Ph.D.

Supervisory Committee

The City University of New York

Abstract

INTERFERENCE AND ENTRAINMENT BETWEEN

MANUAL AND LINGUISTIC ACTIVITIES

by

Carol Sober Alpern

Advisor: Professor Michael-Studdert Kennedy

A verbal-manual interference paradigm assessed the cognitive and/or motoric basis for the association between handedness and the control of language function by the left hemisphere. Twelve normal adult subjects engaged in two kinds of finger tapping tasks (index and sequential finger tapping) while peforming a variety of language tasks. Laguage tasks were contrasted on the basis of their hypothesized degree of left hemisphere dependence: the more left hemisphere dependent were expected to result in greater interference with right hand tapping rates than the less left hemisphere dependent. Experiment 1 contrasted phonetic and semantic tasks; Experiments 1 and 2 contrasted the degree of rhythmicity of the language tasks.

Neither study demonstrated differential laterality effects as a function of the characteristics of the concurrently performed language task. Whether these results reflect brain organization or insensitivity of the technique cannot be determined.

Both studies showed greater interference to right-handed than left-handed tapping rates as a function of speaking in general. However, in Experiment 1, which contrasted input and output tasks, this effect was demonstrated only for output tasks, indicating that lateralized interference is largely motoric. In Experiment 2, the effect was demonstrated only by females, a result difficult to interpret.

Motoric interference was examined further in Experiment 2 (1) by comparing the sequential finger tapping task used in Experiment 1 with an index finger tapping task, and (2) by examining the interaction between tapping and speech output. While the type of tapping task did not differentially affect tapping rate decrements in the dual-task condition, it did affect speech rate decrements: A faster tapping rate, associated with index tapping, and a slower tapping rate, associated with sequential tapping, became entrained with speech, so that speech was significantly faster during index than sequential tapping. Tapping rate also became entrained to speech rate, so that pauses in speech output due to clause boundaries or speech errors resulted in slower tapping rates. Entrainment effects were not lateralized. It was suggested that while structural interference within the left hemisphere could account for lateralized decrements in tapping rates, entrainment may reflect capacity limitations.

ACKNOWLEDGEMENTS

In carrying out a task as difficult as that of completing a dissertation, I was fortunate to have had so supportive an advisory committee. From each committee member I felt at all times a sense of confidence in my efforts; their confidence helped me believe that I could indeed complete the task.

I wish to offer sincere thanks to Professor Lahey whose insightful comments often helped my to clarify the issues. My deep appreciation also goes to Professor Zurif, not only for his intellectual contributions, but for the emotional support which helped my through some of the more difficult days of this endeavor.

To properly thank Professor Boothroyd for the many hours he spent designing the computer programs and other instrumentation for this project is almost impossible. I can truthfully say that without his help this project could never have been carried out. I especially appreciated his patience with one so electronically ignorant as I.

Working with my Chairman, Professor Kennedy, has been an intellectual and emotional pleasure that I shall surely miss. The many hours spent together designing and analyzing this study were stimulating learning experiences for me, and his warmth and concern were greatly appreciated. I feel honored to have had this opportunity.

Special thanks goes to Professor Gerstman who, although not a committee member, gave so much time helping me with the data analysis.

My husband I thank for many things: for never once complaining about how long this effort has taken or about the numerous bad moods brought on as a consequence thereof; for taking time from his own heavy work schedule to care for our son and to prepare so beautifully all the

Figures in this study; and for always being so proud of my accomplishments, an attitude which in itself kept me going.

My son Jesse, whose day-to-day schedule since birth has been determined to some extent by my doctoral studies, I thank for being such an outgoing, adaptable child who never minded being left with baby sitters (or hardly ever!).

Partial support for this thesis was provided by NICHD Grant HD 01994 to Haskins Laboratories, New Haven, Connecticut.

TABLE OF CONTENTS

LIST of TABLES

Text

Appendix D

LIST OF FIGURES

Text

Appendix A

INTRODUCTION

The unique function of the left hemisphere for mediating language has been well documented by a variety of research techniques (e.g. studies of the behavioral effects of localized brain lesions, electroencephalography, dichotic listening). Although the exact nature of left hemisphere specialization for language is not known, there is evidence suggesting that it is the structural aspects of language (i.e. phonological and syntactic processes) rather than the semantic aspects for which the left hemisphere is specialized.

It has also been demonstrated that there is an association between hemispheric control of language and handedness: In more than 99% of all right-handers but in only 60% of left-handers, control of language functioning is located in the left hemisphere (Levy, 1974). This association suggests that common principles may underlie both language and hand functioning, although it is not known whether these commonalities are motoric (e.g. sequencing and rhythmic capacities) or cognitive.

The relation between hand and language function has been demonstrated experimentally by studies showing greater interference with right than left hand performance when verbal and manual tasks are performed concomitantly. The present thesis uses a verbal-manual interference paradigm to assess the nature of this interaction. By examining the kinds of linguistic task that interfere with manual performance and the kinds of manual task that interfere with linguistic performance, the thesis undertakes to determine whether linguistic and manual performance interact at a motor or cognitive level, and thus to clarify the nature of right and left hemiphere differences in normals for speaking and listening to speech.

Theories of Task Interference

Various theories have been put forth to explain interference phenomena. Common to most of these theories is the notion that man possesses a central system of limited capacity and that "two signals which simultaneously require access to the limited system will interfere with each other. Interference is a reduction in the efficiency of processing a signal that is measured by changes in the speed or accuracy of responses to the signal" (Kerr, 1973, p. 401).

This system was first described as a single, limited capacity channel wherein when two signals enter the channel, one is processed while the other is stored until processing of the first signal is completed. Later evidence suggested the need for parallel processing within this limited capacity system (summarized by Kerr, 1973). Moray (1967) characterized the system as being similar to a time-sharing computer which could allocate processing space to various operations. Kahneman (1973,1975) views man as possessing a pool of "effort" which may be allocated to various tasks. Interference occurs when the effort demanded by the simultaneous tasks exceeds the limited capacity of the brain.

Whereas the above models focus on the interference resulting from diversion of attention from one task to another, Kinsbourne and Hicks (1978) suggest a neuro-physiological model based on competition for certain neural structures. According to the functional cerebral space model, there is a limited amount of functional cerebral space available within the human brain; and this cerebral space consists of a highly connected neural network. Interference occurs when two tasks are programmed in close proximity within the same functional cerebral space. Interference is less likely to occur when there is greater functional distance between control centers.

The verbal-manual interference paradigm involves simultaneous performance of a verbal task and a manual task. It has been found that when right-handed subjects perform a verbal task and a manual task concurrently, their right-hand performance on the manual task decreases proportionately more than their left-hand performance (relative to the control condition where the manual task is performed in silence). Kinsbourne's interpretation of this result is that both language and right-handed activity are processed by the left hemisphere and are therefore competing for the use of the same functional cerebral space. As a result, they are more likely to interfere with each other than language and left-handed activity which are programmed in different hemispheres (Kinsbourne and Hicks, 1978).

Review of Verbal-Manual Interference Studies

Both manual tasks and concurrently performed language tasks have been varied by researchers to determine if the type or the difficulty of the tasks alters results.

Variations in Manual Task

The first study to use a manual task simultaneously with a verbal task as an index of hemispheric specialization was carried out by Kinsbourne and Cook (1971). In this study, subjects balanced a dowel rod on the tip of the right or left index fingers. Speaking decreased balancing time on the right hand but increased it on the left hand. Hicks (1975) also found greater right than left hand reductions in dowel balancing when performed concurrently with a verbal task. Only males showed greater interference on the right hand during dowel balancing in a study by Lomas and Kimura (1976).

Several other manual tasks were studied by Lomas and Kimura (1976): single index finger tapping, sequential finger tapping, and sequential arm tapping. In the sequential finger tapping task, subjects were required to tap four telegraph keys in sequence starting with the index finger and moving outward toward the little finger. This sequence was then repeated. In sequential arm tapping, subjects tapped each of the four keys in the same order with a clenched fist so that the whole arm moved across the keys. The most interesting result of this study was that only the sequential manual tasks (both finger and arm tapping) produced greater right than left hand decrements in tapping rate during the dual-task condition. The authors suggest that the reason these tasks resulted in lateralized interference but that non-sequential tasks did not was the functional similarity of the sequential tasks to the skills involved in speaking. Both require rapid placement or positioning of the body without visual feedback.

Lomas (1980) tested the role of visual feedback in the effect by either allowing or eliminating the use of visual feedback during sequential finger and arm tapping. He found that speaking resulted in right-lateralized decrements only in the non-visual feedback condition. Since sequential tapping with visual feedback did not result in lateralized decrements, he concluded that it was not the sequential nature of the tapping task that accounted for the functional similarity to speech, but, as suggested by the earlier study, the need for rapid placement of a body part with minimal visual guidance.

In contrast to the Lomas and Kimura (1976) finding of lateralized decrements for sequential tapping only, is the Bowers, Heilman, Satz, and Altman (1978) study in which single index tapping did produce right-lateralized decrements in tapping rate. Bowers et al. (1978) suggest that the difference between the results of their study and those of Lomas and Kimura (1976) may be due either to differences in the concurrent language tasks employed (to be discussed later) or to the difference in the length of the tapping trial. Bowers et al. (1978) used a 30 second tapping trial, while Lomas and Kimura (1976) used a ten second tapping trial for index tapping. The sequential trials were fifteen seconds in the Lomas and Kimura (1976) study. Lateralized effects may not become apparent until after at least fifteen seconds of tapping.

Sequential and index tapping were compared in a study by Summers and Sharp (1979) with results opposite to those of Lomas and Kimura (1976). Index tapping showed lateralized decrements but sequential tapping did not. No mention is made of control for visual feedback. These authors suggest that tasks involving sequential movements are controlled by both the left and right hemispheres with the left hemisphere controlling the ordering of movements and the right hemisphere controlling the spatial positioning of the movements.

In short, since right-lateralized decrements in tapping rate have been produced with a variety of hand tasks including dowel balancing (Kinsbourne and Cook, 1971; Hicks, 1975; Lomas and Kimura, 1976), index finger tapping (Bowers et al., 1978; Summers and Sharp, 1979; Sussman, Franklin, and Simon, 1982; Klingman and Sussman, 1983), and sequential finger tapping (Hicks, Provenzano, and Rybstein, 1975; Lomas and Kimura, 1976; Hicks, Bradshaw, Kinsbourne, and Feigin, 1978; McFarland and Ashton, 1978a, 1978b; McFarland and Geffen, 1982), the type of hand task is evidently not crucial to the demonstration of lateralized verbal-manual interference effects.

Studies varying the difficulty of the tapping task have also had inconsistent results. Hicks et al. (1978) found that the right-hand lateralized interference effect increased when the complexity of a sequential tapping task was increased. By contrast, McFarland and Ashton (1976b) increased hand task difficulty by varying the distance between two tapping buttons and found that right-hand lateralization (as measured by variability) was eliminated when the buttons were spaced further apart.

Variations in Language Task

The lateralized verbal-manual interference effect has been achieved using a number of different kinds of language tasks. Output tasks have included: repeating a simple sentence (Kinsbourne and Cook, 1971; Hicks et al., 1978), repeating a nursery rhyme (Lomas and Kimura, 1976; Lomas, 1980), reciting automatisms such as the days of the week or months of the year (Sussman et al., 1982; Klingman and Sussman, 1983), reading aloud (Bowers et al., 1978; Sussman et al., 1982), and producing words starting with a given letter (Bowers et al., 1978).

Input tasks have included: silent reading (Bowers et al., 1978), listening to a story (Klingman and Sussman, 1983; Bowers et al., 1978), and listening to instructions (Klingman and Sussman, 1983). Note that all these input tasks were followed by some form of test to ensure that subjects had actually carried out the required task.

Two studies have contrasted the effects of matched input and output versions of a task. Hellige and Longstreth (1981) found an increase in both lateralized and general (bilateral) interference when subjects were reading aloud rather than reading silently. Hicks et al. (1975) compared the effects of silent and vocal rehearsal of lists of letters. They found that vocal rehearsal increased overall interference but that lateralized interference was unchanged.

Language task difficulty has been varied both motorically and cognitively. On the premise that increasing the difficulty of the verbal material would require even greater attention of the left hemisphere to the verbal task and allow less attention to the manual task, Hicks (1975) gave subjects tongue twisters to repeat while dowel balancing. As predicted, subjects' right-handed dowel balancing ability was further decreased when the more complex verbal task was performed concurrently. However, McFarland and Geffen (1982) did not find significant differences between phonetically easy and difficult conditions when performed simultaneously with a sequential finger tapping task.

Varying cognitive difficulty of the language task appears to exert a general effect. Hicks et al. (1975) varied the difficulty of the lists of letters to be recalled after the tapping trial. The easier lists approximated English words to a greater degree than the harder lists. Difficulty of the list resulted in an overall increase in interference with no change in lateralized effects. Hiscock, Kinsbourne, Samuels, and Krause (1983) manipulated memory load in a study of children. They also found a bilateral increase in interference with no change in lateralized results. In contrast, lateralized effects disappeared when memory load was increased in a running-memory-span test by McFarland and Ashton (1978b).

Cognitive difficulty of the language task was suggested by Bowers et al. (1978) as a possible source of the discrepancy between their study's finding of lateralized effects for index tapping and Lomas and Kimura's (1976) finding of lateralized effects only for sequential tapping. The nursery rhyme task used by Lomas and Kimura (1976) was repetitive and automatized whereas Bowers et al. (1978) used a task requiring ongoing processing. Subjects were given a letter and required to produce as many words as possible starting with that letter while tapping. Bowers et al. (1978) suggest that the nursery rhyme task may have been too easy to produce lateralized interference, although results of the above studies (Hicks et al., 1975; McFarland and Ashton, 1978a) suggest that using more difficult tasks does not increase lateralized interference.

In summary, there is some evidence that increased motor interference, either from the verbal task (Hicks, 1975; Hellige and Longstreth, 1981) or the manual task (Hicks et al., 1978) may enhance lateralized interference but that increased cognitive difficulty exerts a generalized effect on interference (Hicks et al., 1975; McFarland and Ashton, 1978a).

General Goals of Experiments 1 and 2

Although the verbal-manual interference paradigm has been used to differentiate language from non-language tasks (Bowers et al., 1978; McFarland and Ashton, 1978a, 1978b; Summers and Sharp, 1979), it has not been used as an index of lateralization of various language tasks. Language tasks in previous studies have been chosen rather arbitrarily. The intent of the present studies is to vary language tasks both linguistically and motorically in order to test various hypotheses about left and right hemisphere language capacities.

Both dichotic listening and tachistoscopic studies have been used to study the differing hemispheric demands of various language tasks. However, these techniques only allow for the study of input tasks of rather low levels of cognitive difficulty. The verbal-manual interference technique, on the other hand, allows for the use of more cognitively demanding tasks; and because it combines speech output with manual activity, the technique also allows for studying the relation between the motor control systems for speaking and hand use. Therefore, the use of the verbal-manual interference paradigm may contribute further to our knowledge of hemispheric specialization for language.

EXPERIMENT 1

Research Questions

Experiment 1 examined three different contrasts in language task: phonetic versus semantic; input versus output; and rhythmic versus non-rhythmic.

Phonetic versus Semantic

Two tasks were used, a rhyme task and a so-called category task. In the rhyme task, subjects were given a word and asked to say aloud as many words that rhymed with it as they could while tapping. In the category task, subjects were given a category and asked to say aloud as many words that belonged to that category as they could while tapping. These tasks were chosen with the goal of examining the differing language abilities of the left and right hemispheres. There is evidence to suggest that the left hemisphere is specialized for the kind of phonetic analysis required to perform a rhyming task (Levy, 1974; Zaidel, 1978b); the right hemisphere, on the other hand, seems to be incapable of analyzing a structure into its component features but can recognize patterns through the matching of a whole pattern. However, the right hemisphere may have a sizeable lexicon, indicating that its capacities are sufficient to establish sound-to-meaning correspondences. Since most of the evidence for these theories comes from pathological populations (Gazzaniga, 1970; Levy, 1974; Dennis and Kohn, 1975; Dennis and Whitaker, 1976; Curtis, 1977; Zaidel, 1978a, 1978b), further study of these ideas in normals is warranted.

Evidence for rhyming as a left-hemisphere ability comes from Levy's (1974) studies of split-brained patients. Her technique involved simultaneous projection tachistoscopically of two different pictures to each hemisphere by joining the left half of one picture with the right half of another. Under these conditions, in a split-brained individual, each hemisphere would believe that it has seen a single stimulus.

A variety of types of stimuli were presented tachistoscopically. Subjects were asked either to point to the item they had seen or verbally to state what they had seen. When the response required pointing, the half of the image flashed to the right hemisphere was generally the one subjects chose. When the response was verbal, subjects generally reported the image seen by the left hemisphere. However, when subjects were asked to point to a picture that rhymed with what they saw, the left hemisphere was dominant. On 82% of the trials, they matched the right-field stimulus indicating strong dominance of the left hemisphere for rhyming. Even when whole unsplit pictures were projected to the left visual field (right hemisphere), thereby eliminating hemispheric competition for responses, the right hemisphere only responded at chance level (Levy, 1974).

Further evidence for left hemisphere specialization for rhyming tasks comes from Zaidel's work with split-brained patients. Zaidel fitted these patients with special contact lenses which allowed for scanning of visual stimuli one hemisphere at a time. He found that the right hemisphere was unable to match a written word to a picture whose name rhymed with it, although unlike with Levy's subjects, the right hemisphere could match two pictures whose names rhymed with each other.

One study of normal adults showed rhyming to be left hemisphere dependent (Moscovitch, 1976). Subjects had to decide whether a printed letter presented tachistoscopically to one visual field at a time rhymed with a previously presented spoken letter. Whether the right or left hand responded, reaction times were faster when the letter was presented to the left hemisphere. The pattern of response times for each hand and hemisphere indicated that the left hemisphere was mediating the task.

The language abilities of the right hemisphere appear to be semantic in nature. For example, Zaidel (1978b) found an extensive auditory vocabulary ability in the right hemisphere. Categorization, the semantic task chosen for the present study, was shown in a tachistoscopic study (Day, 1977) to be mediated equally well by both the right and left hemispheres of normals. Subjects were presented with a category name and a noun and were to press a button if this noun was a exemplar of the category. When the categories were concrete (e.g., animals) as opposed to abstract (e.g., feelings), the right hemisphere was as capable as the left hemisphere of performing the task. However, abstract categorization resulted in left hemisphere reaction time advantages.

Tillman (1975) presents some evidence that the right hemisphere can categorize semantically. Aphasics were studied to see if they could use categorization to aid recall. Although it was found that they did not use categories for recall, they did use categories in a task requiring identification of words as previously heard or not. If many of the previously heard words were a type of fruit, for example, all fruit names would be perceived as previously heard. Words that were not in the fruit category, would generally be identified correctly as not previously heard. If we assume that the right hemisphere was mediating language in these aphasics, then this study provides evidence for right hemisphere categorization ability.

If rhyming is more left hemisphere dependent than categorization, the effect of each on tapping rates may differ. Both rhyming and categorization may result in greater right than left hand interference although the difference between hands might be larger for the rhyming than for the category tasks.

Alternatively, only rhyming may show right-lateralized interference, with categorization showing bilaterally equal interference.

Input versus Output

Experiment 1 used both input and output versions of the rhyme and category tasks. Output versions of the tasks were described above. In the Rhyme Input task subjects were given a word before the start of the tapping trial. While tapping, they listened for a word that rhymed with the given word. Similarly, for Category Input, subjects listened to a list for an exemplar of a particular category. Subjects pressed a button to indicate that they had heard the proper word. Reaction times were measured as an additional method of assessing laterality differences between rhyme and category tasks. Note that since a detection response was required, no post-test entailing recall of the kind used in previous studies was needed here.

Both input and output tasks were included since general and/or lateralized decrements on input tasks have been shown to be weaker than on output tasks (Hellige and Longstreth, 1981; Hicks et al., 1975). More important for the demonstration of hemispheric differences is the possibility that any difference in the localization of the processing of a particular task might be masked by the need for left hemisphere organization of output. Therefore, while output effects may be stronger, use of input tasks may serve to demonstrate the existence of hemisphere differences in the perception of categories and rhymes. The input/output contrast also allows for the examination of how much of the interference produced by this technique reflects cognitive interference and how much reflects motor interference.

Rhythmic versus Non-Rhythmic

Varying the nature of the linguistic tasks in the verbal-manual interference paradigm is a way of examining the special linguistic capacities of the left hemisphere. To study the relation between these and other, non-linguistic capacities of the left hemisphere, we may examine the relation between left hemisphere control for speech and language and left hemisphere control of right-handed manual activity. Evidence from a number of sources suggests that common organizational principles may be shared by both verbal and manual activities. It will be recalled that interference studies by Lomas and Kimura (1976) and Lomas (1980) using sequential finger and arm tapping suggest that what both tasks have in common is the need for rapid placement of a limb (or in the case of speech, the tongue, lips, and jaw) with little or no visual guidance.

Results of an earlier series of studies by Kimura (1976) suggest that "brain regions considered important for symbolic language processes might be better conceived as important for the production of motor sequences which happen to lend themselves readily to communication" (Kimura, 1976 p. 145.) She demonstrated in various ways the apparent overlap in the neural control for speaking and certain motor functions of the right hand. For example, during speaking, there was activation of certain kinds of movements of the right hand only. Another study revealed differing skills of the right hand (sequential movements) versus the left hand (static postures).

Another field of study linking language and manual skill is the study of American Sign Language (ASL). Recent studies of ASL demonstrate that a complex, systematic form of language can be produced in the manual modality (Klima and Bellugi, 1979), and there is evidence that the left hemisphere also mediates this form of language (Kimura, Battison, and Lambert, 1976; Neville and Bellugi, 1978). In a review of Klima and Bellugi (1979) work, Studdert-Kennedy (1980) states:

> The capacity for spoken and manual communication may rest on the evolution not only of the yet unformulated mechanisms that support abstract cognitive functions, but also of the fine, motor sequencing system in the left hemisphere by which those functions are expressed. (p. 106)

Work by Kelso, Tuller, and Harris (1983) demonstrates a mutual interaction between the systems for speaking and manual performance. They found that not only can hand movements be affected by simultaneous speech output but speech output can be affected by simultaneous manual performance. Of relevance to Experiment 1 is their finding on the effect of speech on tapping. Subjects performed a manual task (cyclical flexion and extension of the index finger) while simultaneously repeating the syllable "stack". They were told to vary the stress of alternate syllables in a strong-weak pattern while keeping the amplitude and frequency of finger movements constant. In spite of being told not to change finger movements, waveform analysis showed that finger movements did conform to the stress of speaking. Longer finger movements accompanied stressed syllables and shorter movements accompanied unstressed syllables. In effect, the hand movements became entrained to the speech pattern.

It would seem possible then, that a speech sample characterized by a highly repetitive rhythm and stress pattern might result in manual entrainment: the tapping pattern could become somewhat synchronized with the speech pattern. Based on this possibility, the present study compared a rhythmic sequence (reciting a nursery rhyme) with a non-rhymthic sequence (reciting the months of the year) in order to determine how entrainment affects tapping rates. If subjects varied the amplitudes of their taps to match the regular variation in rate characteristic of a rhythmic speech sample, would there be a greater increase or decrease in tapping rate in the Nursery Rhyme condition compared to the Months condition? Furthermore, would the differences between tapping rates for the two tasks be lateralized, indicating that manual entrainment is a property of the left hemisphere?

In fact, Kelso et al. (1983) found that entrainment was not lateralized to the right hand only. However, the perception of rhyme has been shown to be impaired more by left than by right hemisphere lesions (Milner, 1962; Kimura, 1964). Moreover, there is some evidence that the production of rhythm may be mediated by the left hemisphere. Ibbotson and Morton (1981) had subjects tap a rhythm with one hand and a simultaneous regular beat with the other. Tapping the rhythm with the right hand and the beat with the left hand was much easier than the other way around. The result held for both right handers and most of the left handers. The fact that even the left handers (the majority of whom are left hemisphere dominant for language) were more competent with the right hand at performing the rhythm led these experimenters to conclude that rhythm is related to left hemisphere dominance for language rather than to handedness.

A manual interference task by Johnson and Kozma (1977) also suggested that rhythm may be controlled by the left hemisphere. Subjects balanced a dowel rod while humming unfamiliar melodies. There was a trend toward larger right hand balancing time decrements than left hand balancing time decrements. The authors suggest that the reason the decrease in balancing time was in the same direction as for verbal material was because some aspects of music are mediated by the left hemisphere. It is possible that there was competition between right-handed activity and production of rhythm. Johnson and Kozma (1977) point to a dichotic listening study by Robinson and Solomon (1974) in support of the notion that rhythm is a property of the left hemisphere. Robinson and Solomon (1974) showed that non-speech rhythmic pure-tone patterns carrying no phonetic information are processed in the left hemisphere.

It is possible then that the rhythmic nature of the Nursery Rhyme task would result in not only greater overall decrements in tapping rate but also in greater lateralized decrements in tapping rate.

Summary of Research Questions

In summary, the three questions being addressed in Experiment 1 were: Are phonetic and semantic tasks differentially dependent on left hemisphere mediation? Do input and output versions of the same task result in differences in lateralization? Do rhythm and entrainment interact with finger tapping to increase overall or lateralized interference?

Method

Subjects

Twelve subjects (three males and nine females) obtained from notices around the university and from advertisements in local newspapers were tested. Qualifications were that they be between 18 and 55 years of age, speak English as their first language, and that they reported using their right hand for the following activities: writing, throwing, using a hammer, striking a match, and using a toothbrush. These criteria were taken from Annette (1970) who found that consistency in these five actions was a reliable predictor of hand preference on a fuller questionaire. Subjects were paid $10.00 for participation.

Apparatus

Tapping was done by pressing a telegraph key from which the knob had been removed to eliminate the possibility that two fingers could hit the key at the same time. There were also two telegraph keys (one for each hand), at equal distances to the left and right of the tapping key, for measuring reaction time on monitoring tasks. An Apple II computer with an ISAAC interface measured number of taps per second and reaction time in milliseconds. Subjects listened with binaural headphones to one track of a tape played on an Ampex tape recorder. The second track of the tape had 1000 Hz tones which signaled the computer, via a tone activated switch, to initiate and terminate counting and to measure reaction time to target words. Since the absence of visual feedback has been shown to increase lateralization effects (Lomas, 1980), a screen with an opening for the hand was placed in front of the tapping device. As suggested by Hiscock (1982), a wrist strap was used to minimize arm movements since these may be controlled ipsilaterally. Diagrams and a photograph of the test apparatus can be found in Appendix A, Figures 1-3. The computer program can be found in Appendix B.

Tasks

Hand task. The hand task selected was a sequential finger tapping task similar to the one used by Lomas and Kimura (1976). This task was chosen on the basis of two findings: first, sequential but not index tapping produced lateralized interference (Lomas and Kimura, 1976); and second, increased difficulty of the tapping task increased lateralized effects (Hicks, et al., 1978). Subjects started with the index finger and tapped out in sequence toward the little finger on the same key. Trials lasted 18 to 21 seconds, with only the last 15 seconds of tapping being counted to allow some seconds for tapping rate to stabilize. Some input trials lasted 21 seconds to ensure that the correct response would not always appear after the same amount of time. However, only the 15 seconds before the appearance of the target word was counted. Subjects pressed the reaction time button with their thumb when they heard either "Stop" or a target word; this action ended a trial. Trials alternated between hands. The hand task was performed both in silence (baseline) and concurrently with the language tasks (experimental).

Language tasks. The six concurrent language tasks were as follows:

1. Nursery Rhyme. Subjects were told to repeat over and over as fast as possible, "Mary had a little lamb; its fleece was while as snow; And everywhere that Mary went, the lamb was sure to go."

2. Months of the Year. Subjects repeated the months of the year over and over as fast as possible.

3. Rhyme Input. Subjects listened to a list of words, monitoring for a word that rhymed with a specified target word. The target words were: fair, wail, feet, and fear. These were selected because they had at least 15 common words with which they rhymed. See Appendix C for a complete list of rhyme test words.

4. Category Input. Subjects listened to a list of words, monitoring for a specified target category. The categories were: four-footed animals; pieces of furniture; parts of the human body; and articles of clothing. These categories come from Battig and Montague (1969). Concrete, rather than abstract categories were chosen because Day (1977) found no difference between the right and left hemispheres in classifying words into abstract categories. Monitored words were either one of the top ten responses given for that particular category or were given by 30% of the subjects in the Battig and Montague (1969) norms. The other words in the lists (both rhyme and category) were taken from responses to other categories studied by Battig and Montague (1969). See Appendix C for the complete list of category test words.

5. Rhyme Output. Subjects were asked to say as many words as possible that rhymed with a specified target word. The target words were the same ones as in the rhyme monitoring task.

6. Category Output. Subjects were asked to say as many words as possible that belonged to a specified target category. The target categories were the same as those used in category monitoring.

Procedures

Written instructions were given to the subjects as follows:

> Headphones will be placed on your head. You will hear a tape with some letters and numbers (such as, Bl, A1) followed by the word "go". When you hear "go", tap the center key as fast as you can starting with your index finger and moving out in sequence toward the little finger. Keep the entire forearm on the table and keep your wrist down. Repeat this sequence over and over. When you hear the word "Stop", immediately stop tapping and press the button nearest your thumb. This action ends each trial. Trials alternate between the right and left hands; you will be told which hand to use at the beginning of each trial. Remember to place your hand so that your shortest finger can reach the key. And remember to tap as fast as you can.

Subjects were allowed to try the hand task a few times until they felt comfortable with it. They were given one practice trial per hand using the tape as if it were a real trial. Subjects did not practice the hand task and the language task combined although they heard a sample of rhyme and category input lists. They were familiarized with the tasks by going over the following written instructions for each task with the examiner:

> On some trials you will be doing a listening or a speaking task at the same time you are tapping. When you hear "go", start tapping as you perform one of the following tasks:
>
> 1. Repeat over and over as fast as you can until you hear the word "Stop," "Mary had a little lamb; its fleece was white as snow; And everywhere that Mary went, the lamb was sure to go."
>
> 2. Repeat the months of the year over and over as fast as you can until you can until you hear "Stop."
>
> 3. You will be told to turn over an index card with a word on it. You will hear a list of words. Your job is to listen for a word that rhymes with the word on the card. When you hear the word you think is

correct, stop tapping and quickly press the button nearest your thumb. The word may appear quickly or after a longer period of time.

4. Turn over an index card. While tapping, say out loud as many words as you can that rhyme with the word on the card, until you hear "Stop."

5. You will again listen to a list of words. This time listen for a word that belongs to the category listed on the index card. When you hear the word you think is correct, stop tapping and quickly press the button nearest your thumb. Again, the word may appear quickly or after a longer period of time.

6. Turn over an index card. While tapping, say out loud as many words as you can that belong to the category listed on the card.

There will be several of each kind of task grouped together. You will be told which type task you are on, which hand you are on, and when to turn over a card.

Remember to tap as fast as you can!

There were two baseline and two experimental trials per hand for each of six experimental conditions. Tasks were distributed across subjects in a Latin square format. Half the subjects began with the right hand and half with the left hand. There was one test block for each of the six language tasks; each block began and ended with silent tapping. An example of a test block can be found in Table 1. Testing of each subject was completed in one session of approximately one hour's length.

Table 1

Sample Test Block

for Experiment 1

Trial	Hand	Language Task
1	right	none
2	left	none
3	right	Nursery Rhyme
4	left	Nursery Rhyme
5	right	Nursery Rhyme
6	left	Nursery Rhyme
7	right	none
8	left	none

Results

Data Analysis

Performance changes across conditions were assessed by an index first used by Bowers, et al (1978) which yields a "percent change from baseline" score. The index is:

$$\frac{\text{Baseline tapping rate minus dual tapping rate}}{\text{Baseline tapping rate}}$$

Baseline tapping rate refers to tapping without a concomitant language task; dual tapping rate refers to tapping while performing one of six different language tasks. The purpose of the change index is to normalize tapping rates on the two hands. Positive values of the index indicate performance decrements, that is, reduced tapping rate in the dual task condition; negative values indicate the reverse.

Six analyses of variance were performed. The first compared baseline tapping rates between hands. The next three looked for laterality effects by comparing values of the change index for each hand under various combinations of conditions: 1) all six language tasks combined; 2) output language tasks only; and 3) input and output on the two language tasks that used both these modalities (rhyme and category). Two further analyses of variance were performed on reaction times for the two input language tasks, one on the baseline condition and one on the experimental condition. Performance decrements for right and left hands on individual tasks and on certain other pairings were tested for significance by Scheffé post hoc tests.

All Language Tasks Combined

Table 2 (two left-most data columns) presents baseline tapping rates.[1] As would be expected with right-handed subjects, right hand tapping rates were significantly faster than left hand tapping rates (Mean taps per second: right= 4.14; left=3.68, $p<.001$, Appendix D, Table 1). Although the group mean change index across all tasks (not given in Table 1) was larger for the right hand (5.78) than for the left (3.55), analysis of variance did not reveal a significant hand effect (Appendix D, Table 2). A significant language task by hand interaction ($p=.025$), tested by a series of Scheffé tests yielded no significant differences in hand effects across tasks.

Output Language Tasks

General. Table 2 gives group and individual subjects' mean tapping rates and mean change indices for right and left hands for all output tasks combined. Figure 1 illustrates group mean change indices for all six language tasks combined, for the four output tasks combined, and for the two input tasks combined. It can be seen that when the two input tasks are eliminated, the difference between right and left hand indices increased, resulting in a significant hand effect ($p=.032$; Appendix D, Table 3). Note that the mean change index for the input tasks was slightly greater for the left hand (6.67) than for the right hand (6.06).

[1] Individual subject data found in tables included within the body of the text represent composites of data found in tables included in Appendix E.

Table 2

Mean Baseline and Experimental Tapping Rates and Change Indices for Output Language Tasks in Experiment 1

Subject	Baseline Taps/Second Right	Baseline Taps/Second Left	Test Taps/Second Right	Test Taps/Second Left	Change Index Right	Change Index Left	Difference
1	3.77	3.11	3.62	3.17	4.11	-1.83	5.94
2	3.80	3.10	3.38	2.98	10.83	3.93	6.90
3	4.70	4.38	4.05	3.84	13.90	12.44	1.46
4	4.11	3.81	3.47	3.27	15.47	14.14	1.33
5	5.17	4.96	5.00	5.12	3.14	-3.14	6.28
6	4.00	3.04	4.03	3.54	-.83	-16.39	15.56
7	3.87	3.71	3.50	3.43	9.58	7.63	1.95
8	4.85	3.83	4.82	4.15	.68	-8.41	9.09
9	3.73	3.19	3.64	3.15	2.41	1.35	1.06
10	2.51	2.28	2.49	2.25	.68	1.27	-.59
11	4.20	3.96	3.68	3.39	12.42	14.39	-1.97
12	5.01	4.83	5.25	4.93	-4.86	-2.03	-2.81
$\bar{X}$	4.14	3.68	3.91	3.60	5.63	1.95	3.68

Note. Change indices were originally computed (and entered in the analysis of variance) over scores rounded to three decimal places. The third decimal place has been dropped in this and subsequent tables, so that the tabulated change indices may differ slightly from the values which would be obtained from the numbers appearing here.

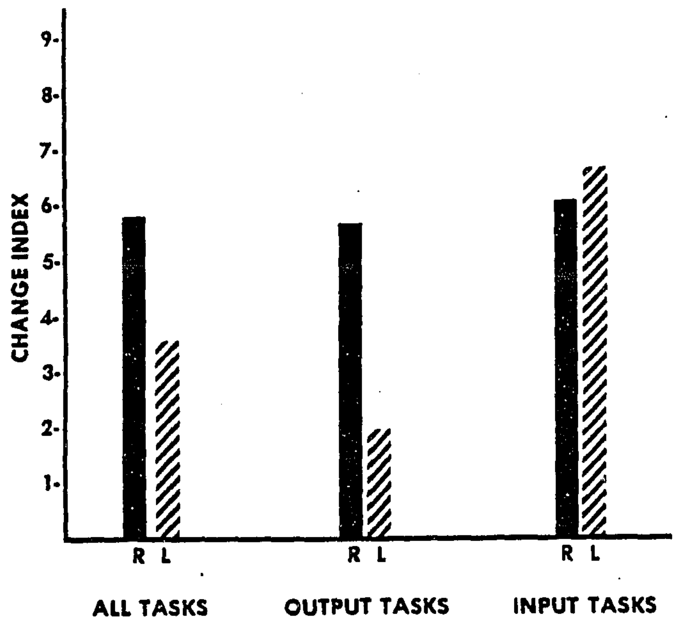


Figure 1. Mean change indices for all language tasks: all 6 tasks combined, all 4 output tasks combined, and both input tasks combined.

The language task by hand interaction for the output tasks alone was not significant (Appendix D, Table 3), indicating that the greater right than left hand decrement was a general effect, not attributable to any particular language task, as long as that task entailed speaking. There was no effect of language task indicating that even without regard to hand, no one task caused significantly greater interference than another.

Rhythmic versus non-rhythmic. Analysis of variance results (Appendix D, Table 3) did not support preliminary findings from a Wilcoxon test that the Nursery Rhyme task was more lateralized than the Months task. However, it is of note that whereas group mean change indices show very little difference between the right and left hands on the Months task (right: 10.05; left: 10.84), there was a 5.19% hand difference on the Nursery Rhyme task, (right: 4.04; left: -1.15). Group and individual subjects' mean change indices and hand differences can be found in Appendix E, Table 1.

Phonetic versus Semantic

Tapping rates. Figure 2 illustrates mean change indices for rhyme and category with input and output for each task shown both separately and combined. Rhyme shows a larger change on the right than on the left for both input and output. Category shows a larger change on the left than on the right for input and on the right than on the left for output. Preliminary findings from a Wilcoxon test showed greater lateralization for the Category Output task than for the Rhyme Output task. However this was not verified by analysis of variance which gave no significant main effects or interactions (Appendix D,Table 4). The modality (input/output) by hand interaction just missed significance ($p= .051$). Group and individual subjects' change indices for Rhyme and Category Input tasks can be found in Appendix E, Table 2; for Rhyme and

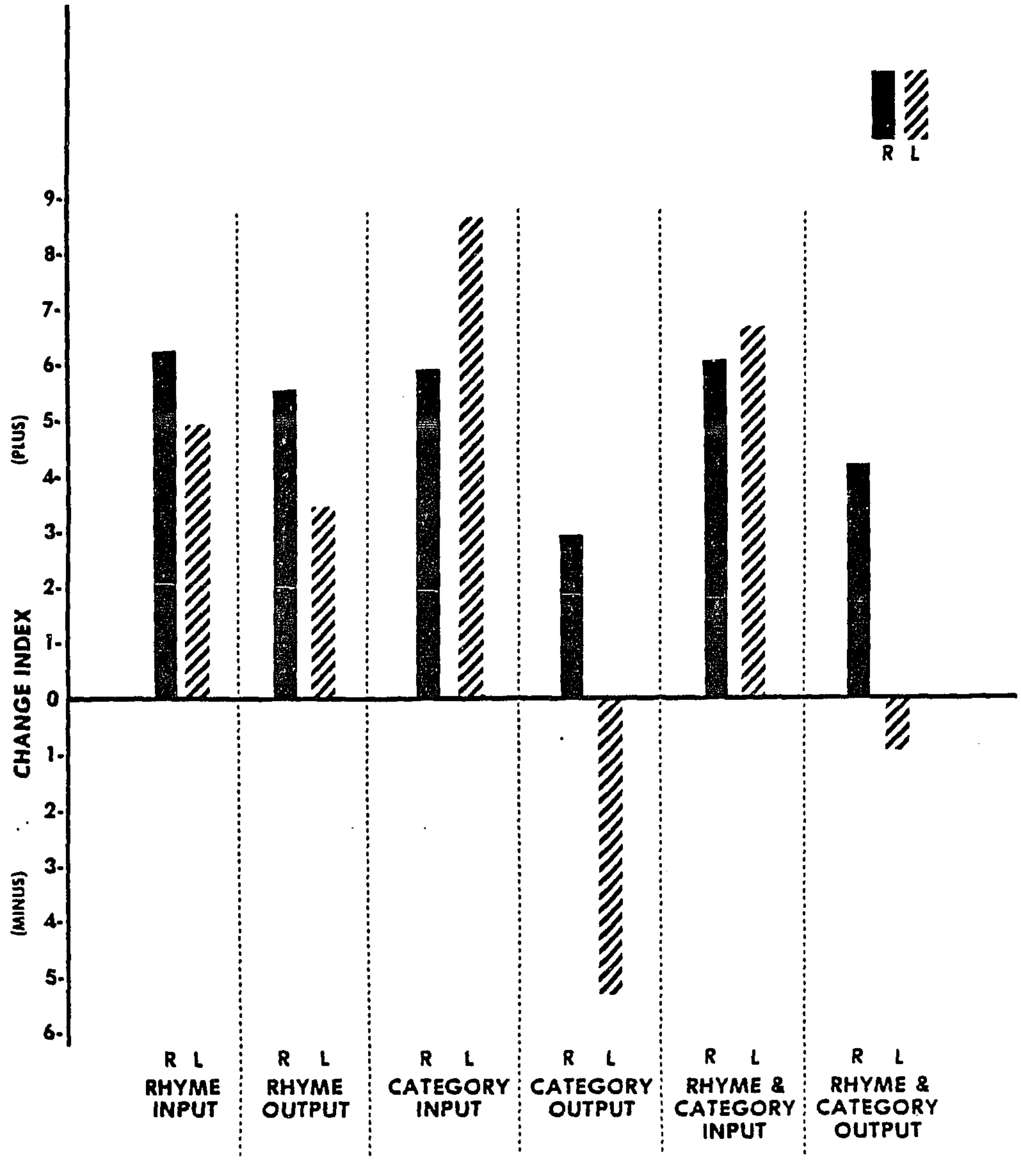


Figure 2. Mean change indices for rhyme and category language tasks: input and output individually and combined.

Category Output tasks in Appendix E, Table 3. Inspection of those tables will suggest that substantial individual differences were sufficient to drown the group effects apparent in the mean values of Figure 2.

Reaction times. In a further attempt to assess lateralized differences between rhyme and category input tasks, reaction times to the stimuli presented in these two tasks were analyzed. The first analysis of variance examined baseline reaction times, that is, simple reaction times to the word "Stop". There was no significant difference between baseline reaction times for the two hands ($p>.500$, Appendix D, Table 5; means: right=640 ms.; left=639ms.). Therefore, there was no need to use a change index, and reaction times were examined directly. Results of analysis of variance found no significant main effects or interactions (Appendix D, Table 6). Subjects' mean reaction times for each task and hand are found in Appendix E, Table 4.

Atypical Effects

In the dual task condition, the expected result is a decrease from baseline tapping rate with that decrease being greater on the right hand than the left. In a number of instances, individuals actually showed improved tapping rates in the dual task condition, an effect that we will term facilitation. There were also individuals who showed greater left than right hand tapping decrements on a particular task.

Facilitation. Out of 144 indices (each of 12 subjects had 6 right hand and 6 left hand scores), 52 or 36% were facilitatory. Somewhat more facilitation occurred on the left (30 out of 72 or 42%) than on the right (22 out of 72 or 31%), and more occurred on output tasks (41 out of 96 or 43%) than input tasks (11 out of 48 or 23%). Group mean indices showed facilitation in two instances, both output tasks (Nursery Rhyme and Category Output), and both on the left hand (Nursery Rhyme: left= -1.15; Category Output: left= -.98). However, Wilcoxon analysis never demonstrated a significant facilitation effect on either hand for any task.

Left hand indices. For some individuals, the left hand, rather than showing facilitation, actually showed larger change indices than the right hand. Greater left than right decrements were also seen in group means for the Months task (right: 10.05; left: 10.84), the Category Input task (right: 5.86; left: 8.62), and the Input tasks combined (right: 6.06; left: 6.67). However, neither analysis of variance nor Wilcoxon analysis found significantly greater left than right hand indices.

Discussion

Input versus Output

The major result of Experiment 1 was that lateralized interference with tapping was found only when language tasks requiring speech output were performed concomitant with tapping. When language tasks did not involve speech output, interference was general. This result supports the view that lateralized interference between manual and verbal tasks occurs at the level of motor programming rather than at the level of cognitive processing. Lomas and Kimura's (1976) interpretation of lateralized interference as due to motor similarity between speaking and sequential tapping is consistent with the finding of this study.

Other evidence that the interference occurs at the motor level of programming can be found in two studies which combined non-verbal vocalization with a manual task. Hicks (1975) found that concurrent humming selectively interfered with right-handed dowel balancing. Hicks et al. (1978) found greater right-hand interference when sequential tapping was performed while "tra-la-ing" a tune.

Nonetheless, as indicated in the introduction, several studies have demonstrated lateralized interference from language tasks requiring no verbal output (Bowers, et al., 1978; Hellige and Longstreth, 1981; Hicks, et al., 1975; Summers and Sharp, 1979). What is the origin of the difference between the present study and these others? One factor is the use/non-use of a recall task. There is evidence from Spoehr and Corin (1978), Campbell and Dodd (1980), and Crowder (1983) that short term memory engages an articulatory representation. These studies found mutual interference with short term memory between lip read words and auditorily presented words. This interference indicates that words seen but not heard (lip read) and words heard but not seen (auditorily presented) are stored in some common articulatory or motoric code.

While the recall studies of interest to this study involve relatively long-term memory (up to several minutes) rather than short-term memory (less than ten seconds), it is possible that this articulatory representation may also be engaged as part of the initial process of longer term storage. If so, we would expect motoric interference with any language task that required recall. This interpretation is consistent with Hellige and Longstreth's (1981) finding that lateralized decrements occurred only when subjects were told to expect a recall test after silent reading in the dual task condition. Bowers et al.'s (1978) suggestion of subvocal interference is also consistent with a motoric interpretation.

Finally, it should be noted that written rather than auditory (or lip read) input was used in most of the verbal-manual interference studies cited above. Written stimuli have not been shown to involve motoric interference in short-term memory studies, but when memory is over a longer span, subjects may employ sub-vocal vocalization to aid recall. The possibility that long-term memory, even when stimuli are presented in a written form, might engage motoric processes would be a fruitful area for further research.

Rhythmic versus Non-Rhythmic

It will be recalled that the Nursery Rhyme versus Months contrast was aimed at answering the question of whether a task with a repetitive, predictable rhythmic pattern (Nursery Rhyme) would show a different overall and/or lateralized pattern of interference than the recitation of a non-rhythmic list (Months). It was hypothesized that the rhythmic component of the nursery rhyme would cause entrainment with tapping such that rhythmic patterns in the speech would result in rhythmic patterns in tapping. Furthermore, this entrainment might be lateralized due to a left hemisphere component of rhythm (Robinson and Solomon, 1974; Johnson and Kozma, 1977; Ibbotson and Morton, 1981). Although preliminary Wilcoxon tests found larger right than left hand change indices for the Nursery Rhyme task, but not for the Months task, full analysis of variance found no significant difference in change indices for the two tasks. Therefore, no contribution of rhythm to asymmetries in verbal-manual interference was demonstrated.

Phonetic versus Semantic

The phonetic versus semantic comparison was designed to test the hypothesis that while certain semantic tasks (such as categorization) may be mediated equally well by the right and left hemispheres, a phonetic task such as rhyming is solely dependent on the left hemisphere. It was reasoned that if the right hemisphere participated more in the processing of the Category task than in the processing of the Rhyme task, there would be less left hemisphere interference and therefore smaller right hand change indices for the Category task than for the Rhyme task. Results of analysis of variance found no difference between change indices or reaction times for the Rhyme and

Category tasks in either the input or output conditions. Therefore, rhyme and category skills were not demonstrated to have different degrees of left hemisphere dependence.

This result could be interpreted as support for the view that language processing occurs in the right hemisphere only when forced by pathology of the left hemisphere. Certainly, much of the evidence for right hemisphere processing of language comes from pathological populations (Gazzaniga, 1970; Levy, 1974; Dennis and Kohn, 1975; Dennis and Whitaker, 1976; Curtis, 1977; Zaidel, 1978a, 1978b).

Alternatively this result could simply reflect a lack of sensitivity of the verbal-manual interference technique to differences in degree of laterality. Although, as mentioned previously, many studies have demonstrated different patterns of lateralization for language and non-language tasks combined with a manual task (Bowers et al., 1978; McFarland and Ashton, 1978a, 1978b; Summers and Sharp, 1979; Hellige and Longstreth, 1979), no studies using several different language tasks have yet shown a difference in lateralized effects between language tasks (Sussman, Franklin, and Simon, 1982; Klingman and Sussman, 1983). In the present study, both the rhythmic versus non-rhythmic contrast and the rhyme versus category contrast were attempting to demonstrate different degrees of left hemisphere mediation. While it is possible that such differences do not exist, it is also possible that the technique is simply not sensitive to differences within left hemisphere tasks.

In summary, the major result of Experiment 1 is the finding of a strong motor component to the lateralized interference occurring between verbal and manual tasks. This study showed lateralized decrements only when input tasks were eliminated; other studies have shown lateralized effects from input tasks. However, these have only occurred for tasks requiring some form of post-task recall. Since recall may engage some form of articulatory representation, the lateralized effects of these input tasks may also reflect motor interference.

EXPERIMENT 2

Research Questions

The major focus of Experiment 2 was the further study of the interaction between speech and tapping from a motoric point of view. All language tasks required overt verbalization and were paired with two kinds of tapping tasks. It should be noted that Experiment 2 was planned on the basis of the preliminary analysis of Experiment 1, mentioned above, indicating that the Nursery Rhyme task was more lateralized than the Months task. Therefore, language tasks were designed that would examine further the role of speech rhythm in lateralized interference and to test for possible mutual entrainment between speech and tapping.

Three language tasks were used in Experiment 2. The Nursery Rhyme task was repeated again as an example of speech output with a repetitive, predictable rhyme. In contrast, a prose passage with the same number of syllables as the nursery rhyme but without the sing-song rhythm was tested. Finally, Bowers et al.'s (1978) verbal fluency task was replicated. This single-word output task allowed for the examination of the effects of a non-rhythmic and non-syntactic task on the speech-tapping interaction.

These tasks also allowed for measuring possible differential effects due to cognitive demands of the task. The Nursery Rhyme task used familiar, automatized material whereas the Prose task required memorization of an unfamiliar passage. The Fluency task put the greatest cognitive demand on the subject by requiring ongoing processing to produce a constantly changing output.

As mentioned earlier, Kelso et al., 1983, found that not only can finger movements become entrained to speech patterns but speech patterns can become entrained to finger movements. When subjects alternated long and short movements of the index finger, it was found that longer finger movements were associated with increased stress of word production. Therefore, for all three tasks, samples of speech output were measured both with and without tapping. In this way, not only could the effects of speech on tapping be measured, but also the effects of tapping on speech and the interaction between them.

All language tasks were performed with two different tapping tasks: the same sequential tapping task used in Experiment 1, and single index finger tapping. In this way, the discrepancy between Lomas and Kimura's (1976) finding that only sequential tapping resulted in lateralized decrements and Bowers et al.'s (1978) finding that index tapping resulted in lateralized decrements could be further examined. One suggested explanation for the conflicting findings is the difference in language tasks used. It is possible that the nursery rhyme task used by Lomas and Kimura (1976) was not cognitively demanding enough to produce lateralized decrements with index tapping. Since language tasks from both studies were incorporated, it could be determined whether the difference in language tasks accounts for their differing results. The use of two different tapping tasks also allowed the examination of possible differential effects of the tapping task on the speech output. For example, although Bowers et al. (1978) found no effect of index tapping on speech output, sequential tapping with the same language task might result in decrements in speech output.

Another factor suggested as a possible cause for the difference in results for the two tapping tasks is the length of the tapping trial. Lomas and Kimura (1976) used a 10 second trial for index tapping and a 15 second trial for sequential tapping. Bowers et al. (1978) used a 30 second trial for index tapping. Ten seconds might have been too short for lateralized decrements to become apparent. Therefore, measures of lateralized decrements were made after 10, 20, and 30 seconds of tapping.

In summary, Experiment 2 examined how speaking and tapping interact to produce lateralized and/or generalized interference. The questions being addressed were: Does the degree of rhythmicity of language output determine the degree of lateralization? Do the cognitive demands of the language task affect interference? Does tapping interfere with speech? If so, is that interference lateralized? Is there mutual entrainment between speech and tapping? If so, is that entrainment lateralized? Does the nature of the hand task differentially affect tapping and/or speech output? What is the effect of the length of the tapping trial on lateralization?

Method

Subjects

Subject criteria were the same as in Experiment 1 except that an equal number of males and females (six of each) were run. Subjects did not include any who participated in Experiment 1. $10.00 was again paid for participation.

Apparatus

The tapping device was the same as in Experiment 1 although the two reaction time keys were removed. The computer kept a running count of the total number of taps at all points in the 30 second trial and measured mean inter-tap intervals across all points in the trial. A free-field tone generated by the computer signaled subjects when to start and stop. Subjects' verbal responses were recorded on one track of a cassette tape, and the telegraph key taps were recorded on the second track. Diagrams and a photograph of the testing apparatus can be found in Appendix A, Figures 4-6. Computer programs can be found in Appendix B.

Tasks

Each subject performed two different hand tasks both alone and concurrently with three different language tasks. Each trial ran 30 seconds as in the Bowers et al. (1978) study.

Hand task. One task consisted of single index finger tapping. The other task was the same sequential tapping task as was performed in Experiment 1. Both tasks were performed in silence and concurrently with the language tasks. Trials alternated between hands.

Language tasks.

1. Nursery Rhyme. Subjects repeated over and over the following: "Mary had a little lamb; its fleece was white as snow; And everywhere that Mary went, the lamb was sure to go."

2. Prose. Subjects repeated over and over again the following: "When I woke up this morning, it was snowing; so I left early. Driving was slow, but I got to work on time." This passage contains the same number of syllables as the nursery rhyme.

3. Fluency. Subjects spoke as many words as possible beginning with a specified letter, excluding proper names and derivatives. The letters were: A, B, C, D, F, G, H, M, P, R, S, and T.

Procedure

Written instructions were given to the subjects as follows:

> When you hear a signal, start tapping with your index finger as fast as you can keeping the forearm and wrist down. Keep tapping until you hear the signal again. Trials alternate between hands. You will be told which hand to use at the beginning of each trial. Remember to tap as fast as you can!

After one practice trial per hand, subjects were given the following instructions for the sequential tapping task:

> On some trials you will be doing a different kind of tapping task. When you hear the signal, start tapping the center key with your index finger, moving out in sequence toward the little finger. Repeat this sequence over and over until you hear the signal again. Trials alternate between hands. Keep the wrist and forearm down. Always place your hand so that your shortest finger can reach the key. And remember to tap as fast as you can.

Subjects were given one practice trial per hand with the tones. No practice was given for the language tasks but subjects were familiarized with the tasks by going over the following instructions with the examiner:

> On some trials you will be doing one of the following speaking tasks either alone or at the same time you are tapping:
>
> 1. When you hear the first tone, start tapping and repeating over and over the nursery rhyme, "Mary had a little lamb; its fleece was white as snow; And everywhere that Mary went, the lamb was sure to go."
>
> 2. When you hear the first tone, start tapping and repeating over and over the sentences, "When I woke up this morning it was snowing; so I left early. Driving was slow, but I got to work on time." Stop tapping and speaking when you hear the second signal. The sentences will be reviewed prior to doing this task.
>
> 3. Before each trial, turn over an index card. A letter will be written on that card. When you hear the tone, start tapping and at the same time saying as many words as you can think of that start with that letter.
>
> You will be told which tapping task and which verbal task to do next. There will be a series of each. Remember to tap as fast as you can while attempting to divide attention equally between tapping and speaking.

There were two trials per hand for each of six experimental conditions:

1. Nursery Rhyme with single index finger tapping
2. Prose with single index finger tapping
3. Fluency with single index finger tapping
4. Nursery Rhyme with sequential finger tapping
5. Prose with sequential finger tapping
6. Fluency with sequential finger tapping

The total number of trials for the experimental condition was 24. There were 16 baseline tapping trials (4 per hand for index tapping and 4 per hand for sequential tapping). Language and hand tasks were distributed across subjects in a Latin square format. Half of the subjects started with the right hand and half with the left hand. The initial test block for Subject 1 can be found in Table 3.

The next test block had only six trials since it did not start with baseline tapping but instead started with the Prose language task. The test pattern was: 2 baseline; 4 experimental; 2 baseline; 4 experimental; 2 baseline; 4 experimental; 2 baseline, at which point all three language tasks would have been performed with index tapping. The sequence was then repeated with sequential tapping. Subject 2 did the same sequence starting with the left hand. All subjects started and ended with baseline tapping.

There were 8 baseline speech trials: 1 Nursery Rhyme, 1 Prose, and 2 Fluency trials at the beginning of the session; and 1 Nursery Rhyme, 1 Prose, and 2 Fluency trials at the end of the session. (Having 4 rather than 2 baseline Fluency trials, allowed each letter to be used an equal number of times in the baseline, index, and sequential conditions.) The order in which these were presented to each subject coincided with the order presented him in the dual-task condition. Letters for the Fluency task were varied over baseline and experimental conditions in a Latin square format.

Testing of each subject was completed in one session of approximately one hour's length.

Results: Tapping Rate Decrements and Variability

Data Analysis

Performance was again assessed by the change index. Indices were calculated for the first 10, first 20, and first 30 seconds of tapping. For each time period two analyses of variance were performed. One compared baseline

Table 3

Sample Test Block for

Experiment 2

Trial	Hand	Hand Task	Language Task
1	right	index	none
2	left	index	none
3	right	index	Nursery Rhyme
4	left	index	Nursery Rhyme
5	right	index	Nursery Rhyme
6	left	index	Nursery Rhyme
7	right	index	none
8	left	index	none

performance over hands, hand tasks, and sex; the other compared indices across these conditions and the three language tasks. Change indices for right and left hands on certain pairings were tested for significance by Scheffé post hoc tests. Two further analyses of variance compared the standard deviations of tapping rates over the full 30 seconds under the conditions cited above.

Tapping Rates: Baseline

Results of analysis of variance on baseline tapping rates at 10, 20, and 30 seconds are found in Appendix D, Tables 7, 8, and 9 respectively. The right hand was found to be significantly faster than the left hand at all three time intervals (10 seconds: $p=.011$; 20 and 30 seconds: $p<.001$). Figure 3 shows the mean number of taps per second across all hand tasks for each hand at 10, 20, and 30 seconds. There was a slight decrease in tapping rate from 10 seconds to 30 seconds.

The difference between index and sequential tapping was also significant (10, 20, and 30 seconds: $p<.001$). Index tapping was faster than sequential tapping at all time intervals as can be seen in Figure 4.

The significant hand task by hand interaction (10 seconds: $p=.016$; 20 seconds: $p=.005$; 30 seconds: $p=.006$) was tested by the Scheffé method. At ten seconds there was a significant difference between right and left hands for index tapping ($p=.01$) but none for sequential tapping. At 20 and 30 seconds the difference between right and left hand tapping rates was significant for both index tapping ($p=.001$) and sequential tapping ($p=.05$). Figure 5 illustrates the greater hand difference for index than for sequential tapping.

Tapping Rates: Experimental

Analysis of variance results for change indices at 10, 20, and 30 seconds can be found in Appendix D, Tables 10, 11, and 12 respectively. There were

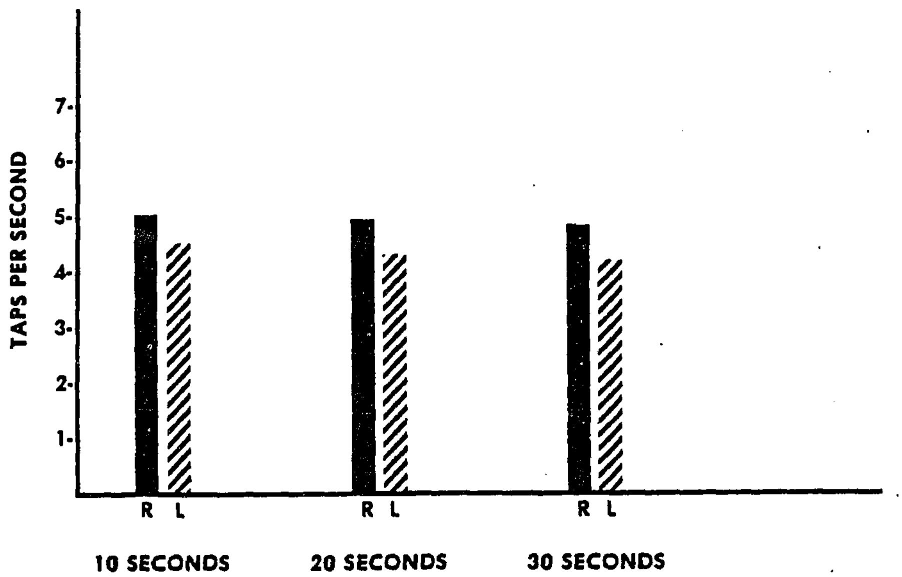


Figure 3. Mean number of baseline taps per second for each hand at each time interval, across hand tasks.

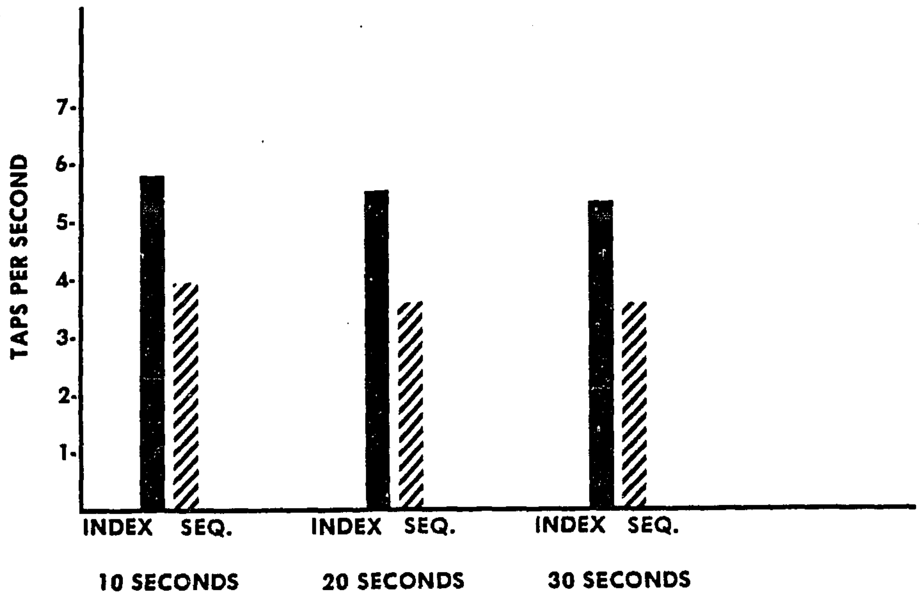


Figure 4. Mean number of baseline taps per second for index and sequential tapping at all time intervals.

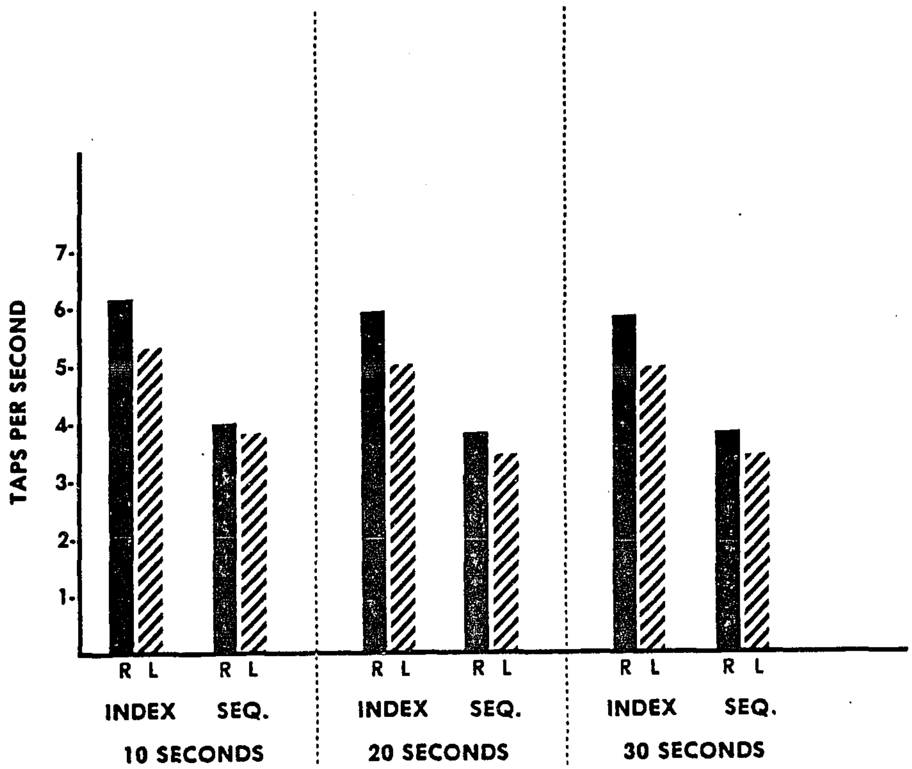


Figure 5. Mean number of baseline taps per second for each hand and hand task at all time intervals.

significant main effects for hand and language task, and significant interactions for sex by hand and for language task by hand.

Hand. There was a significant overall difference between right and left hand tapping indices at 20 seconds (p=.007, Appendix D, Table 11) and at 30 seconds (p=.001, Appendix D, Table 12) but not at 10 seconds (Appendix D, Table 10). Figure 6 illustrates the group mean change index for each hand at each time interval. The difference between hands increased with time from a 2.5% hand difference at 10 seconds to a 3.3% hand difference at 30 seconds. Group and individual subjects' mean tapping rates and mean change indices at 10, 20, and 30 seconds can be found in Tables 4, 5, and 6 respectively.

Was the significant difference between hands at 20 and 30 seconds due to larger right hand decrements or smaller left hand decrements? Examination of group means reveals that indices were smaller for both hands at 30 seconds than at 10 seconds, but the difference between the right hand at 10 seconds and the right hand at 30 seconds was less (1.8%) than the difference between the left hands (2.6%). In other words there was slightly less interference on the left hand over time. This effect was especially strong for females who, as will be seen below, were responsible for the lateralized effects. In females, the left hand showed a 4% reduction in interference from 10 to 30 seconds whereas the right hand showed only a 1.6% reduction in interference over time. In males, the reduction in interference was approximately the same for both hands (l=1.4%; r=1.5%).

Sex by hand. A significant sex by hand interaction at 20 seconds (p=.004, Appendix D, Table 11) and 30 seconds (p<.001, Appendix D, Table 12) reveals that the hand effect was due to the females in the study. Scheffé tests showed that right and left hand indices of females differed (20 seconds: p=.01; 30 seconds: p=.001) but right and left hand indices of males did not differ. Figure 7

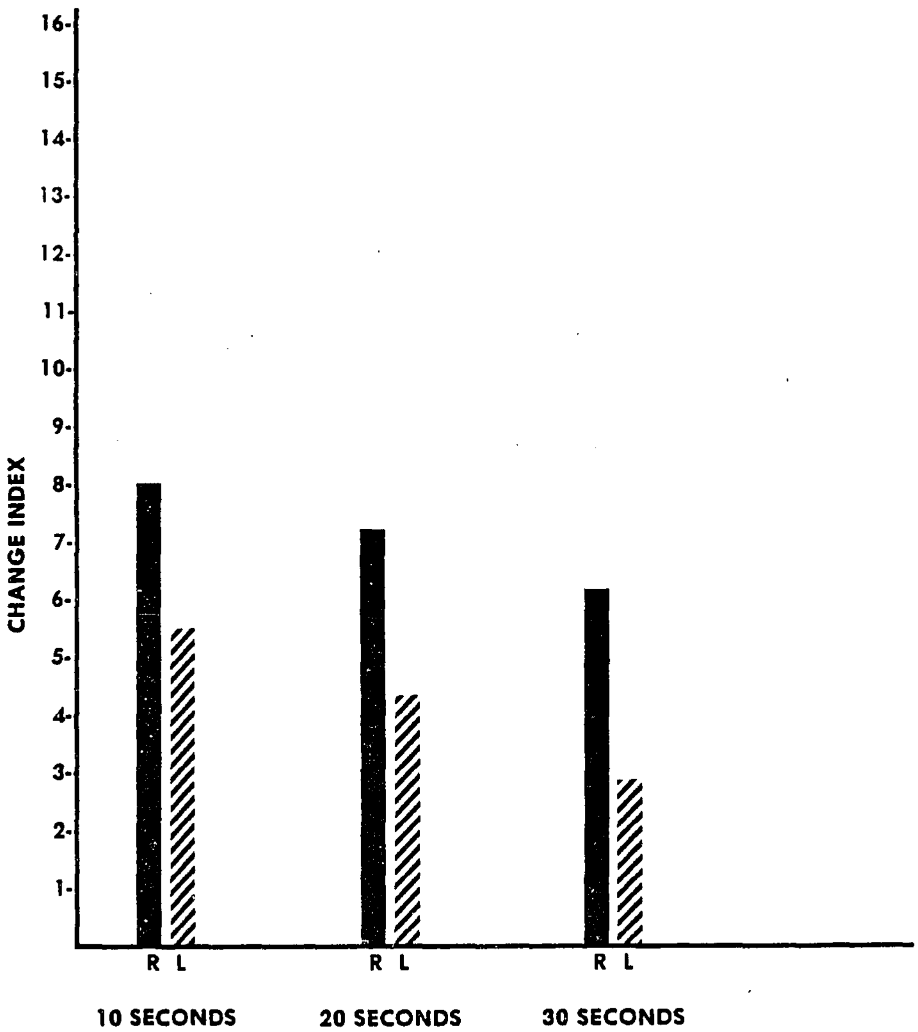


Figure 6. Mean change indices for each hand at all time intervals, across all language and hand tasks.

Table 4

Change Indices for All Tasks Combined: 10 Seconds

	Baseline Taps/Second		Test Taps/Second		Change Index		Difference
Subject	Right	Left	Right	Left	Right	Left	
1	5.86	4.86	5.41	4.70	7.68	3.29	4.39
2	5.37	4.63	4.32	3.75	19.55	19.01	.54
3	4.86	4.05	3.76	3.53	22.63	12.84	9.79
4	3.98	3.73	3.95	3.60	.75	3.49	-2.74
5	5.24	4.63	4.85	4.47	7.44	3.46	3.98
6	6.05	5.05	5.78	4.95	4.46	1.98	2.48
7	4.70	4.20	4.25	4.15	9.57	1.19	8.38
8	5.99	5.53	5.25	5.05	12.35	8.68	3.67
9	3.83	3.68	3.68	3.52	3.92	4.35	-.43
10	5.25	4.76	5.08	4.83	3.24	-1.47	4.71
11	4.79	3.89	4.75	4.03	.84	-3.60	4.44
12	4.93	4.56	4.75	3.98	3.65	12.72	-9.07
$\overline{X}$	5.07	4.46	4.65	4.21	8.00	5.50	2.50

Table 5

Change Indices for All Tasks Combined: 20 Seconds

	Baseline Taps/Second		Test Taps/Second		Change Index		Difference
Subject	Right	Left	Right	Left	Right	Left	
1	5.50	4.79	5.22	4.56	5.09	4.80	.29
2	5.19	4.53	4.28	3.78	17.53	16.56	.97
3	4.73	3.84	3.62	3.39	18.82	11.72	7.10
4	3.67	3.51	3.76	3.51	-2.45	.28	-2.73
5	5.00	4.36	4.71	4.30	5.80	1.38	4.42
6	5.80	4.82	5.53	4.68	4.66	2.90	1.76
7	4.41	3.86	3.97	3.93	9.98	-1.81	11.79
8	5.62	5.08	4.97	4.81	11.57	5.31	6.26
9	3.69	3.54	3.51	3.34	4.88	5.65	-.77
10	5.17	4.61	4.96	4.66	4.06	-1.08	5.14
11	4.62	3.68	4.63	3.82	-.22	-3.80	3.58
12	4.85	4.37	4.52	3.93	6.80	10.07	-3.27
$\overline{X}$	4.85	4.25	4.47	4.06	7.21	4.33	2.88

Table 6

Change Indices for All Tasks Combined: 30 Seconds

	Baseline Taps/Second		Test Taps/Second		Change Index		Difference
Subject	Right	Left	Right	Left	Right	Left	
1	5.33	4.73	5.20	4 .50	2.50	4.93	-2.43
2	5.10	4.27	4.30	3 .80	15.69	10.94	4.75
3	4.67	3.80	3.67	3 .43	21.43	9.65	11.78
4	3.63	3.50	3.73	3 .50	-2.75	0	-2.75
5	4.90	4.23	4.67	4 .20	4.76	.79	3.97
6	5.70	4.76	5.50	4 .57	3.51	4.20	-.69
7	4.37	3.83	3.97	3 .90	9.16	-1.74	10.90
8	5.43	4.80	4.93	4 .73	9.20	1.39	7.81
9	3.63	3.53	3.53	3 .37	2.75	4.72	-1.97
10	5.10	4.53	4.97	4 .63	2.61	-2.21	4.82
11	4.53	3.63	4.63	3 .87	-2.21	-6.42	4.21
12	4.90	4.33	5.53	3 .97	7.48	8.46	-.98
$\overline{X}$	4.77	4.16	4.47	4.04	6.18	2.89	3.29

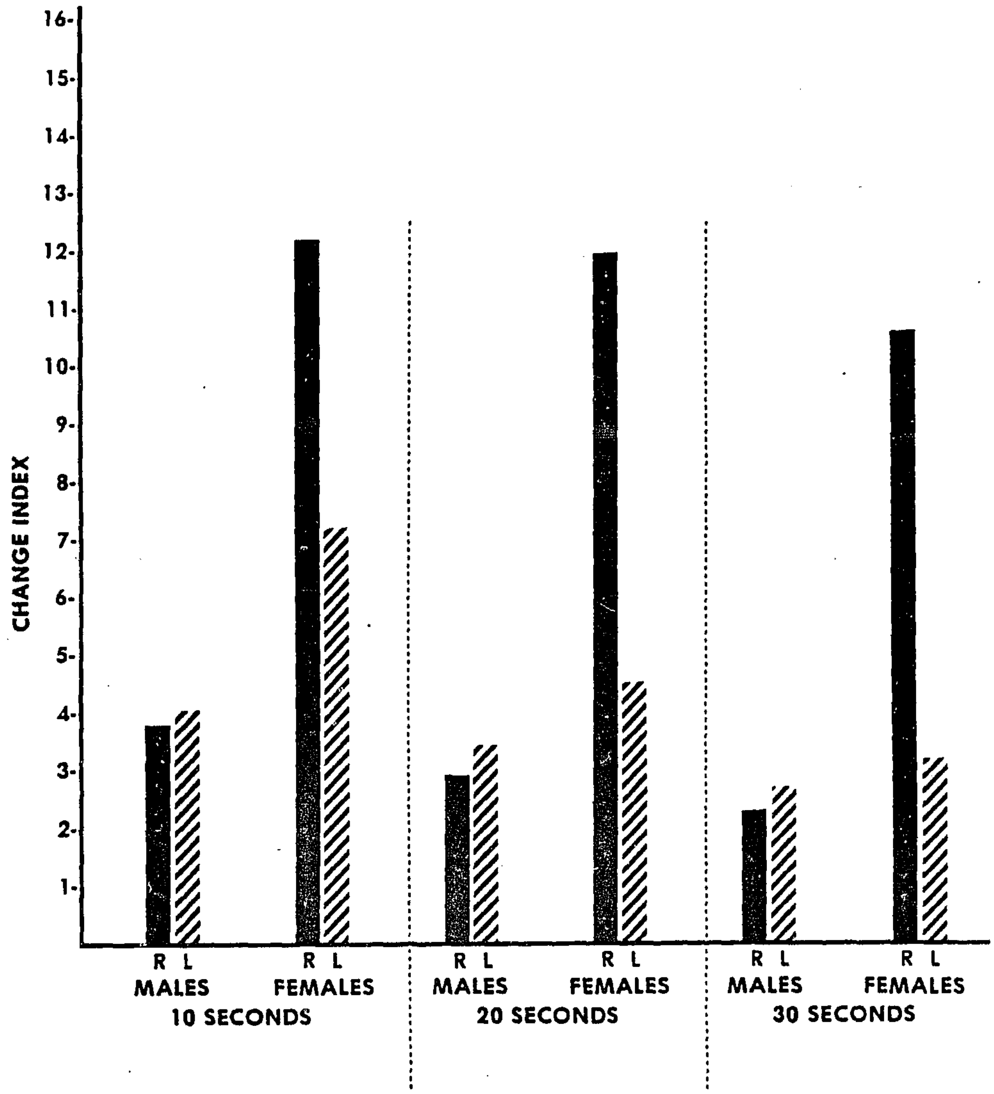


Figure 7. Mean change indices on each hand for males and females at all time intervals, across all language and hand tasks.

illustrates right and left indices for males and females at 10, 20, and 30 seconds. Note that male indices showed low levels of interference on both hands, minimal difference between hands, and slightly greater left than right hand indices.

Language task. Language task was significant at all time intervals (10 and 20 seconds: $p<.001$, Appendix D, Tables 10 and 11; 30 seconds: $p=.001$, Appendix D, Table 12). Post hoc test using the Scheffé showed that the Fluency task resulted in greater interference than the Nursery Rhyme and Prose tasks (10 seconds: $p=.01$; 20 and 30 seconds: $p=.05$). The difference between the Fluency task and the Nursery Rhyme task alone was even more highly significant ($p=.001$, all time intervals).

Although not significantly different from each other, group means for the Prose task were greater than for the Nursery Rhyme task at all time intervals. Figure 8 illustrates the consistently greater group mean change indices for the Fluency task followed by Prose and finally Nursery Rhyme. It is also apparent from Figure 8 that change indices on the Fluency task decreased with time.

Language task by hand task by hand. This interaction was significant at 20 seconds only ($p=.04$, Appendix D, Table 11). The Scheffé test yielded no significant differences in hand effects across tasks. For the most part, the Fluency tasks differed from the other tasks but this was already shown in the language task effect. Of possible interest is that during sequential tapping, the right hand of the Nursery Rhyme task differed significantly from the right hand of the Prose task ($p=.01$). Appendix E, Tables 9-14 give individual and group change indices and hand differences for each language task under each hand task condition at 10, 20, and 30 seconds. Males and females are grouped separately to illustrate the larger hand differences for females as compared to males.

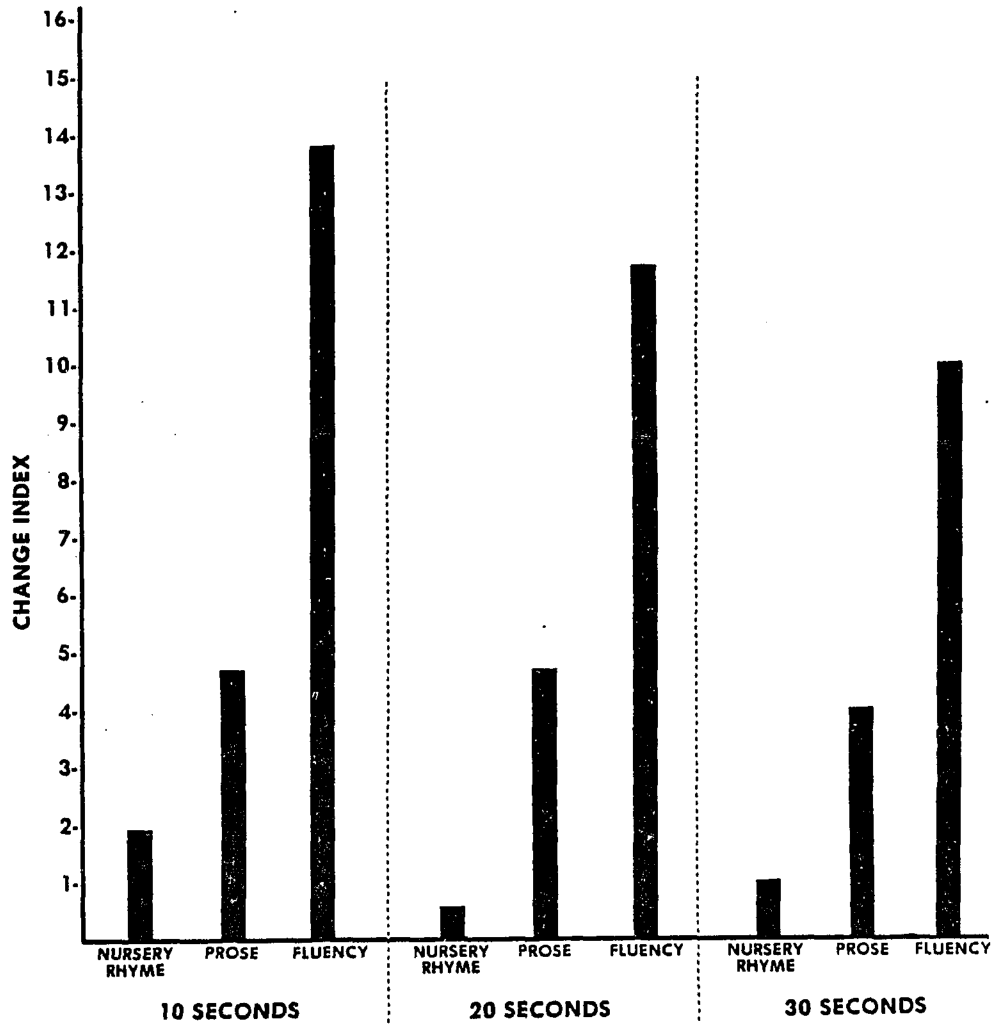


Figure 8. Mean change indices for each language task at all time intervals, across hand tasks.

Nonsignificant Effects

Neither language task by hand nor hand task were significant on the analysis of variance, but some comments about each may be informative.

Language task by hand. Examination of group mean change indices for each language task at all time intervals (Appendix E, Table 11 (10 seconds), Table 12 (20 seconds), and Table 13 (30 seconds) shows the Fluency task to have the greatest difference between hands. The Prose task had the next largest hand difference and the Nursery Rhyme task had the smallest hand difference. All tasks showed a decrease in decrements from 10 to 30 seconds and an increase in hand differences (Figure 9). It was previously mentioned when discussing hand differences in general that the increase in lateralized differences from ten to thirty seconds was due to adaptation of the left hand. When group means for each language task at ten and thirty seconds are compared, this pattern is shown to be true for all tasks, although the Fluency task showed the greatest left hand adaptation of all the language tasks.

Hand task. Examination of group mean change indices for index and sequential tapping at each time interval (Appendix E, Tables 14-16) shows larger hand differences for index tapping than sequential tapping especially for males alone. Since the difference between the right and left hands in the baseline condition at 20 and 30 seconds was more significant for index tapping ($p=.001$) than for sequential tapping ($p=.05$), and since change indices are derived from baseline rates, it would not be surprising if sequential tapping in the experimental condition showed less lateralized results.

Atypical Effects

Facilitation. The amount of facilitation in Experiment 2 (30 seconds) was approximately the same as in Experiment 1. Out of 144 indices, 45 or 31% were facilitatory; in Experiment 1, 36% were facilitatory . As in the first experiment,

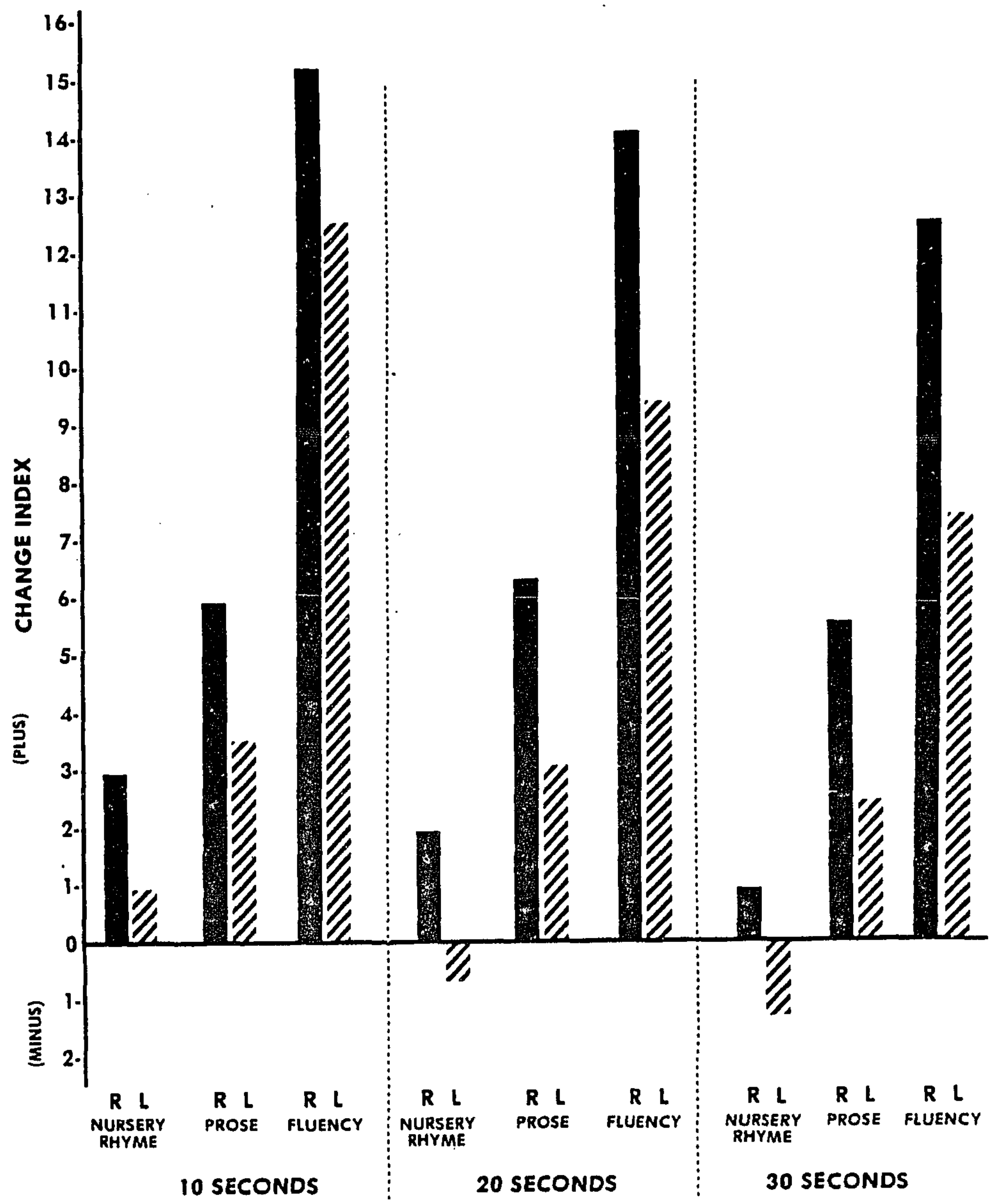


Figure 9. Mean change indices for right and left hands of each language task at all time intervals, across both hand tasks and sexes.

facilitation occurred somewhat more on the left (27 out of 72 or 38%) than on the right (18 out of 72 or 25%). The task with the most instances of facilitation, Nursery Rhyme (21 indices), resulted in the least amount of interference. The task with the fewest instances of facilitation, Fluency (9 indices), caused the most interference. Index and sequential tapping had approximately the same number of indices indicating facilitation (index: 21; sequential: 24). Males had twice as much facilitation as females (males: 30; females: 15).

Group mean change indices at 30 seconds showed facilitation on both hands of the Nursery Rhyme/Sequential task (right: -2.06; left: -2.08). When male and female mean indices were examined separately, males showed facilitation on both hands of the Prose/Index task (right: -1.42; left: -.19) and on both hands of the Nursery Rhyme/Sequential task (right: -10.06; left: -5.17). Females showed facilitation only on the left hand of the Nursery Rhyme/Sequential task (- .5). It will be recalled that in Experiment 1, the mean left hand index of the Nursery Rhyme/Sequential task also showed facilitation. As in Experiment 1, facilitation was not significant for any hand on any task. There was one exception: males showed significant facilitation on a Wilcoxon matched-pairs test ($p<.05$) for the right hand of the Nursery Rhyme/Sequential task.

Left hand indices. Greater left than right hand indices also occurred in many individual trials but this effect was never significant. There were no group means in which left hand decrements were greater than right hand decrements except when males were considered alone. For males, the group mean percent decrement on the Fluency/Sequential task was greater on the left (15.9) than on the right (14.9).

Tapping Variability

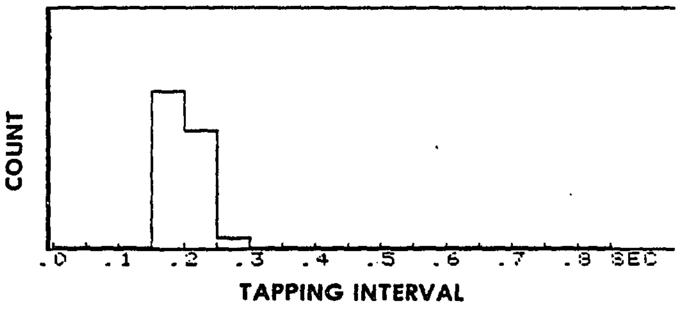
Baseline. Results of the analysis of variance of the mean standard deviation of the time interval between taps in the baseline condition can be found in Appendix D, Table 13. Results revealed no difference between the right and left hands or between males and females on variability of tapping rate. Hand task was significant ($p<.001$) with sequential tapping being more variable (Mean standard deviation=120.2ms) than index tapping (Mean standard deviation=33.2ms). Figure 10 is a computer generated graph (see Appendix B, Computer Program: Experiment 2—Histogram) illustrating the greater variability of a baseline sequential tapping trial compared to a baseline index tapping trial.

Experimental. Results of the analysis of variance of the mean standard deviation of the time interval between taps in the dual task condition can be found in Appendix D, Table 14. As in the baseline condition, there were no significant hand or sex effects, but hand task was significant ($p=.005$). Sequential tapping was more variable (mean standard deviation=150.8 ms) than index tapping (mean standard deviation=40.8) as illustrated in Figure 11.

Also significant was language task ($p=.01$). Post hoc analysis using the Scheffé test showed the Fluency task to be significantly more variable ($p=.01$) than the Nursery Rhyme task. This result mirrored tapping rate results which showed the Fluency task to result in the greatest change indices. Mean standard deviations for each task also paralleled tapping rate results in that the mean standard deviation of the time interval between taps was greater for Fluency (120.2 ms) than for Prose (95.0 ms) which was greater than Nursery Rhyme (71.2 ms). It appears that the language task that caused the greatest change in tapping rate also caused the most variability although the hand task that was most variable did not result in greater tapping rate change indices. Figure 12 is

—Baseline/Index—

MSEC	COUNT
Ø TO 49	Ø
5Ø TO 99	Ø
1ØØ TO 149	Ø
15Ø TO 199	83
2ØØ TO 249	62
25Ø TO 299	5
3ØØ TO 349	Ø
35Ø TO 399	Ø
4ØØ TO 449	Ø
45Ø TO 499	Ø
5ØØ TO 549	Ø
55Ø TO 599	Ø
6ØØ TO 649	Ø
65Ø TO 699	Ø
7ØØ TO 749	Ø
75Ø TO 799	Ø
8ØØ PLUS	Ø



—Baseline/Sequential—

MSEC	COUNT
Ø TO 49	Ø
5Ø TO 99	Ø
1ØØ TO 149	Ø
15Ø TO 199	3Ø
2ØØ TO 249	74
25Ø TO 299	6
3ØØ TO 349	4
35Ø TO 399	5
4ØØ TO 449	2
45Ø TO 499	1
5ØØ TO 549	Ø
55Ø TO 599	Ø
6ØØ TO 649	1
65Ø TO 699	Ø
7ØØ TO 749	1
75Ø TO 799	1
8ØØ PLUS	Ø

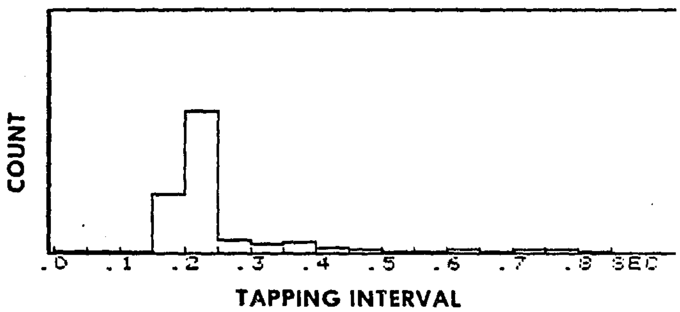
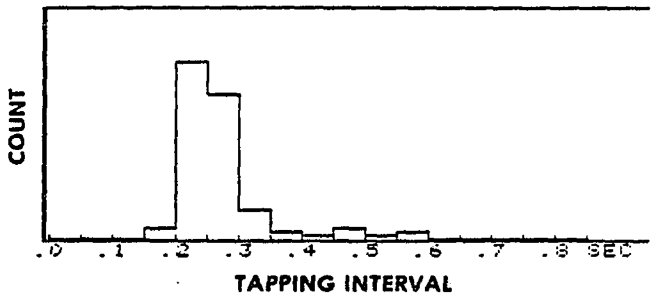


Figure 10. Variability in tapping rate: Baseline/index tapping trial compared to baseline/sequential tapping trial.

—Experimental/Index—

MSEC	COUNT
Ø TO 49	Ø
5Ø TO 99	Ø
1ØØ TO 149	Ø
15Ø TO 199	3
2ØØ TO 249	49
25Ø TO 299	4Ø
3ØØ TO 349	8
35Ø TO 399	2
4ØØ TO 449	1
45Ø TO 499	3
5ØØ TO 549	1
55Ø TO 599	2
6ØØ TO 649	Ø
65Ø TO 699	Ø
7ØØ TO 749	Ø
75Ø TO 799	Ø
8ØØ PLUS	Ø



—Experimental/Sequential—

MSEC	COUNT
Ø TO 49	Ø
5Ø TO 99	Ø
1ØØ TO 149	1
15Ø TO 199	Ø
2ØØ TO 249	14
25Ø TO 299	46
3ØØ TO 349	11
35Ø TO 399	7
4ØØ TO 449	6
45Ø TO 499	2
5ØØ TO 549	1
55Ø TO 599	1
6ØØ TO 649	Ø
65Ø TO 699	1
7ØØ TO 749	Ø
75Ø TO 799	Ø
8ØØ PLUS	3

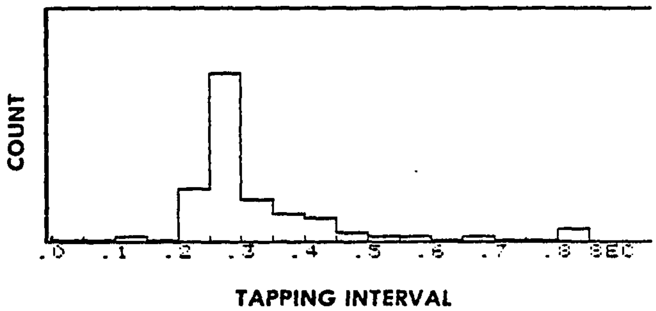
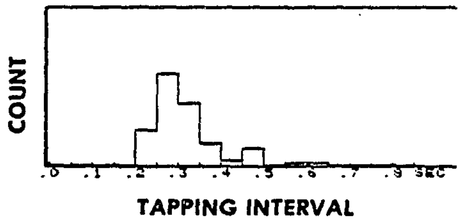


Figure 11. Variability in tapping rate: Experimental/index trial compared to experimental/sequential trial.

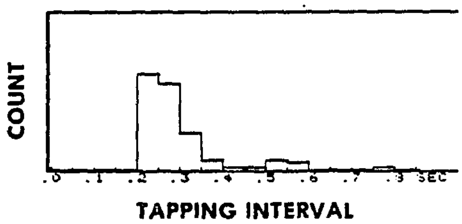
—Nursery Rhyme/Sequential—

MSEC	COUNT
0 TO 49	0
50 TO 99	0
100 TO 149	0
150 TO 199	0
200 TO 249	14
250 TO 299	37
300 TO 349	25
350 TO 399	9
400 TO 449	2
450 TO 499	7
500 TO 549	0
550 TO 599	1
600 TO 649	1
650 TO 699	0
700 TO 749	0
750 TO 799	0
800 PLUS	0



—Prose/Sequential—

MSEC	COUNT
0 TO 49	0
50 TO 99	0
100 TO 149	0
150 TO 199	0
200 TO 249	39
250 TO 299	35
300 TO 349	15
350 TO 399	4
400 TO 449	1
450 TO 499	1
500 TO 549	4
550 TO 599	3
600 TO 649	0
650 TO 699	0
700 TO 749	0
750 TO 799	1
800 PLUS	0



—Fluency/Sequential—

MSEC	COUNT
0 TO 49	0
50 TO 99	0
100 TO 149	0
150 TO 199	0
200 TO 249	12
250 TO 299	18
300 TO 349	20
350 TO 399	8
400 TO 449	1
450 TO 499	3
500 TO 549	2
550 TO 599	1
600 TO 649	2
650 TO 699	2
700 TO 749	0
750 TO 799	1
800 PLUS	5

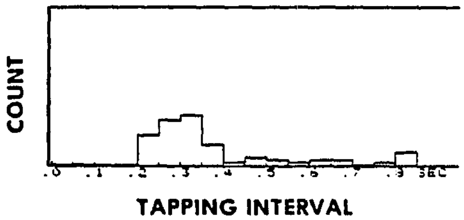


Figure 12. Variability in tapping rate: Comparison of Nursery Rhyme, Prose, and Fluency language tasks.

a graphic representation of tapping rate variability for one trial each of the Fluency, Prose, and Nursery Rhyme tasks.

Results: Interactions between Speech and Tapping

Data Analysis

Speech rate changes. Data were analyzed at thirty seconds only. Three analyses of variance examined changes in baseline across language task and sex, and changes in speech output from the baseline condition (speaking without tapping) to the experimental condition (concomitant speaking and tapping). The Fluency task was analyzed separately from the Nursery Rhyme and Prose tasks due to the difference in the kind of speech output the Fluency task involved.

For the Nursery Rhyme/Prose analysis, the number of syllables spoken per trial was counted. The trials were averaged to obtain the mean number of syllables for each hand of each language task (index and sequential considered separately). In the baseline condition, the mean number of syllables spoken was compared across language task and sex. For the experimental analyses, the difference between the number of syllables spoken in the baseline and the experimental condition was analyzed across the above conditions plus hand and hand task.

The mean number of words rather than the mean number of syllables was used in the Fluency analysis of variance since the subjects' task was to produce as many words as possible regardless of their length. No baseline analysis of variance was performed since only one language task was involved. The number of words spoken in the experimental condition was subtracted from the number of words spoken in the baseline condition, and these differences were compared across hand, hand task, and sex.

Speech-tapping relation. A fourth analysis of variance examined the relation between speech output and abnormally long intervals between taps. Data from only three subjects were analyzed as this analysis was considered exploratory in nature.

Since computer analysis provided the interval in milliseconds between each pair of successive taps and the mean interval between taps for each trial, it was possible to locate in the data unusually long intervals between taps. The criteria for determining unusually long intervals was that there be either one interval three standard deviations above the mean interval for that trial, or two intervals in sequence, each two standard deviations above the mean for that trial. The first instance of an interval meeting either of these criteria in each trial was then located by scanning the print-out of intervals between taps.

By means of a specially designed computer program (see Appendix B, Experiment 2--Playback), it was possible to locate on a tape recording of the speech output, the utterances produced during any specific interval selected. The number of syllables occuring during that interval was counted, and based on the length of time of the interval, the number of syllables per second was calculated. The number of syllables per second over an entire trial was also calculated to give an overall speech rate. These two numbers were analyzed to determine if the syllable rate during the long tapping intervals differed from the overall syllable rate.

Only the Prose and Nursery Rhyme language tasks were analyzed since the irregularity of the Fluency output did not lend itself to this type of analysis. Each trial was analyzed separately so that for each subject there were eight right-handed and eight left-handed trials (four index and four sequential per hand) for a total of 48 samples for all three subjects. Factors in the analysis of variance were hand task, language task, hand, state (overall or interval), and trial number.

In addition to looking for changes in rate of speech output, the content of the speech output during long intervals was examined to see if there was any pattern to the kind of speech occurring. For example, was there a large percentage of pauses between phrases, or were subjects stumbling over words? Although not included in the analysis of variance, speech output during long intervals in the Fluency task was also examined to see if subjects stopped tapping while they were thinking of a word or if they were more fluent in these intervals.

Speech Rate Changes: Nursery Rhyme and Prose

Baseline. Results of the analysis of variance of baseline speech rates can be found in Appendix D, Table 13. Language task was significant (p=.002) with the Nursery Rhyme task being faster (Mean=213.1 syllables or 7.1 repetitions of the passage per 30 second trial) than the Prose task (Mean=187.7 syllables or 6.2 repetitions of the passage per trial). This result is important because even though the two tasks were designed so that both had the same number of syllables, subjects were slower to repeat the Prose passage. It is probable that the familiarity of the nursery rhyme allowed subjects to repeat it with greater ease than the prose passage which required memorization of new material. Therefore, the two tasks were not, as had been intended, matched in all ways except in the rhythmic/non-rhythmic component.

Experimental. Analysis of variance results for speech rate decrements (Appendix D, Table 16) show hand task to be the only significant result (p=<.001). Examination of the data revealed that only sequential tapping interfered with speech output (Figure 13). The mean decrement for sequential tapping was 21 syllables, almost equal to the total number of syllables (27) in

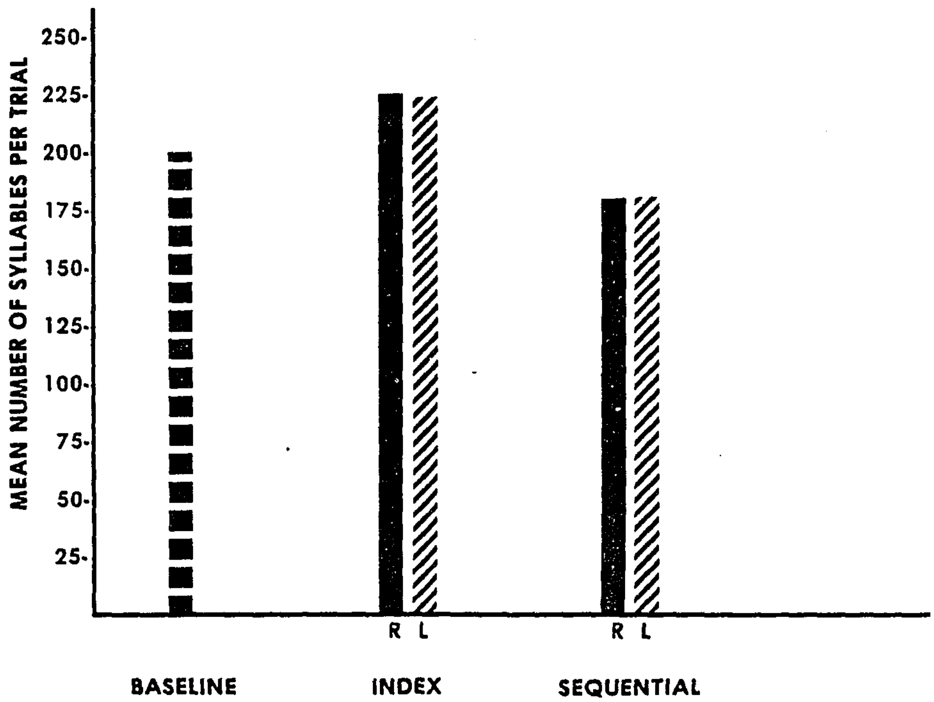


Figure 13. Mean number of syllables spoken during baseline, index tapping, and sequential tapping conditions (Nursery Rhyme and Prose tasks).

one recitation of a passage. This decrement was shown to be significant on a Wilcoxon test (T=9; P=.02,two-tailed). The mean for index tapping actually showed facilitation with a mean increase of 24 syllables during tapping. In fact, Wilcoxon analysis showed this increment to be significant (T=3,p<.01,two tailed). Note the lack of a difference in speech output as a function of hand in both index and sequential tapping (Figure 13). Individual speech output data can be found in Appendix E, Table 17.

Speech Rate Changes: Fluency

Results of the analysis of variance for speech rate changes on the Fluency task can be found in Appendix D, Table 17. Hand task was again the only significant effect (p=.013). Sequential tapping produced a mean decrement of 1.13 words from the baseline condition, whereas the mean decrement for index tapping was .03 words. In neither case were these decrements shown on the Wilcoxon test to be a significant change from baseline. In other words, although sequential tapping slowed speech output more than did index tapping, tapping did not actually interfere significantly with performance on the Fluency task. Baseline and experimental speech rates for each subject can be found in Appendix E, Table 18.

Speech-Tapping Relation

Results of analysis of variance are found in Appendix D, Table 18. There was a significant difference (p=.004) between the number of syllables per second over the whole trial (mean 6.027) and the number of syllables per second in the long inter-tap intervals (mean 4.354). Significant interactions included hand by trial number (p=.038), hand by state by trial number (p=.02), and hand task by language task by state by trial number (p=.03). Results of Scheffé testing of these interactions were irrelevant to the question being examined. Individual data on the number of syllables per second over the whole trial and during intervals can be found in Appendix E, Table 19.

The above analysis of variance clearly shows that when tapping rate slows down, speech rate slows down. To gain a better understanding of this relation, language output during these intervals was examined to see if the nature of the speech output was related to the slowdown in tapping. It was found that in 36 of the 48 intervals examined, speech output consisted of the end of one phrase and/or the beginning of another, points at which speakers generally slow down either for a breath, or to mark the end of one thought and the beginning of another. Three of the intervals contained false starts or stumbling over a word, both of which interrupt the flow of speech and serve to reduce the syllables per second output. In all, 81% of the long inter-tap intervals could be attributed to entrainment of tapping to speech. Appendix E, Table 20 lists the mean interval for each trial, the length of the interval examined, and the speech output during that interval for each subject.

Figures 14-17 illustrate through spectrographic analysis the relation between the speech and the taps during the inter-tap interval examined; the heavy vertical lines correspond to taps. Figure 14 pictures sequential tapping during the Prose task. A 979 ms interval between taps occurs as the subject says the last word in the phrase "I got to work on time," followed by a breath before tapping and speaking are initiated again.

Figure 15 illustrates index tapping during the Prose task; again a clause ending occurs during the long interval (620 ms). The interval contains the last two words of the phrase "this morning it was snowing". In this case however, the subject starts tapping again while taking a breath before initiating the next phrase.

Stumbling over a word during the Nursery Rhyme (sequential tapping) task is illustrated in Figure 16. The subject finished the phrase "had a little lamb"

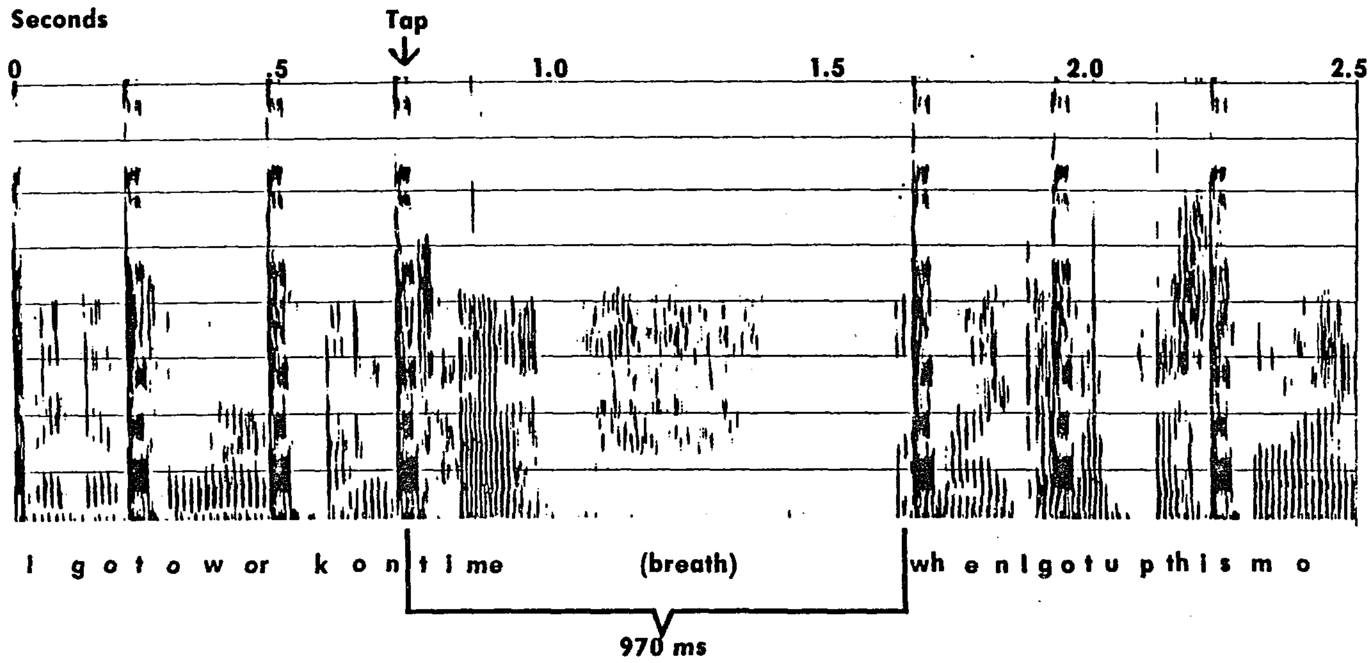


Figure 14. Spectrograph of subject saying, "I got to work on time, when I got up this mo(rning)...."

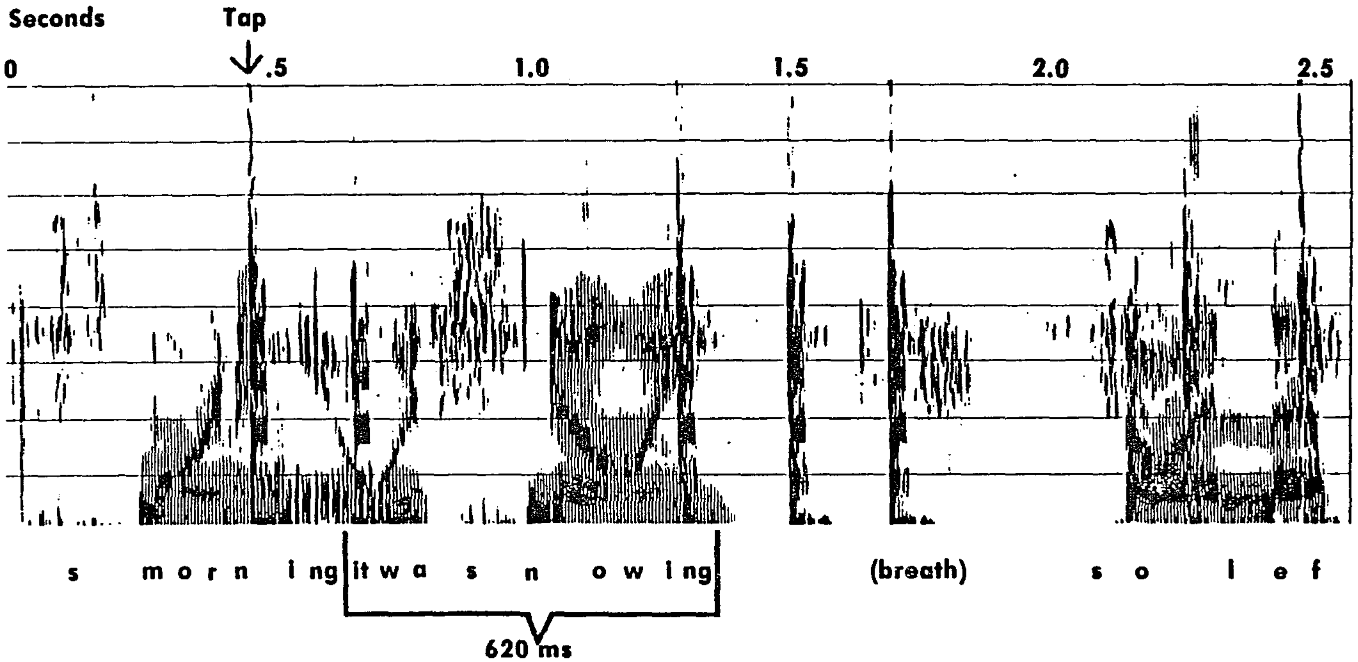


Figure 15. Spectrograph of subject saying, "(Thi)s morning it was snowing, so I left....."

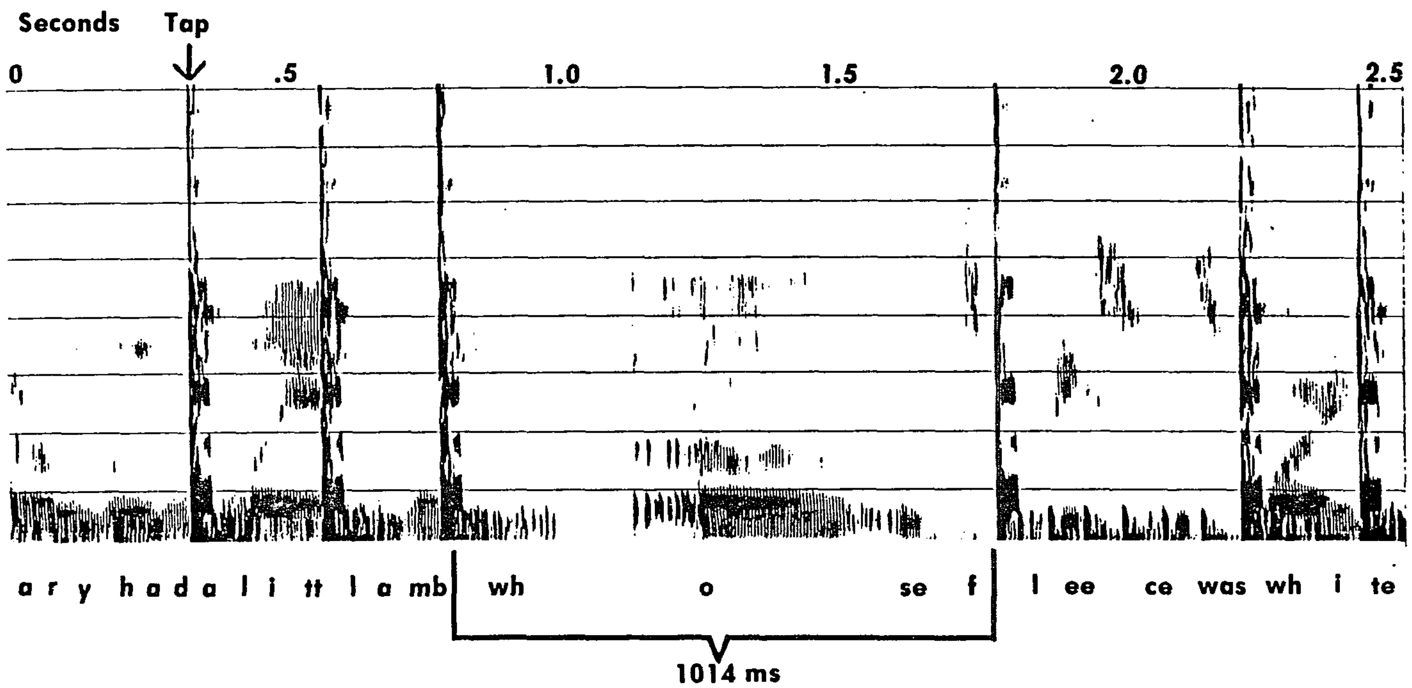


Figure 16. Spectrograph of subject saying, "(M)ary had a little lamb, whose fleece was white...."

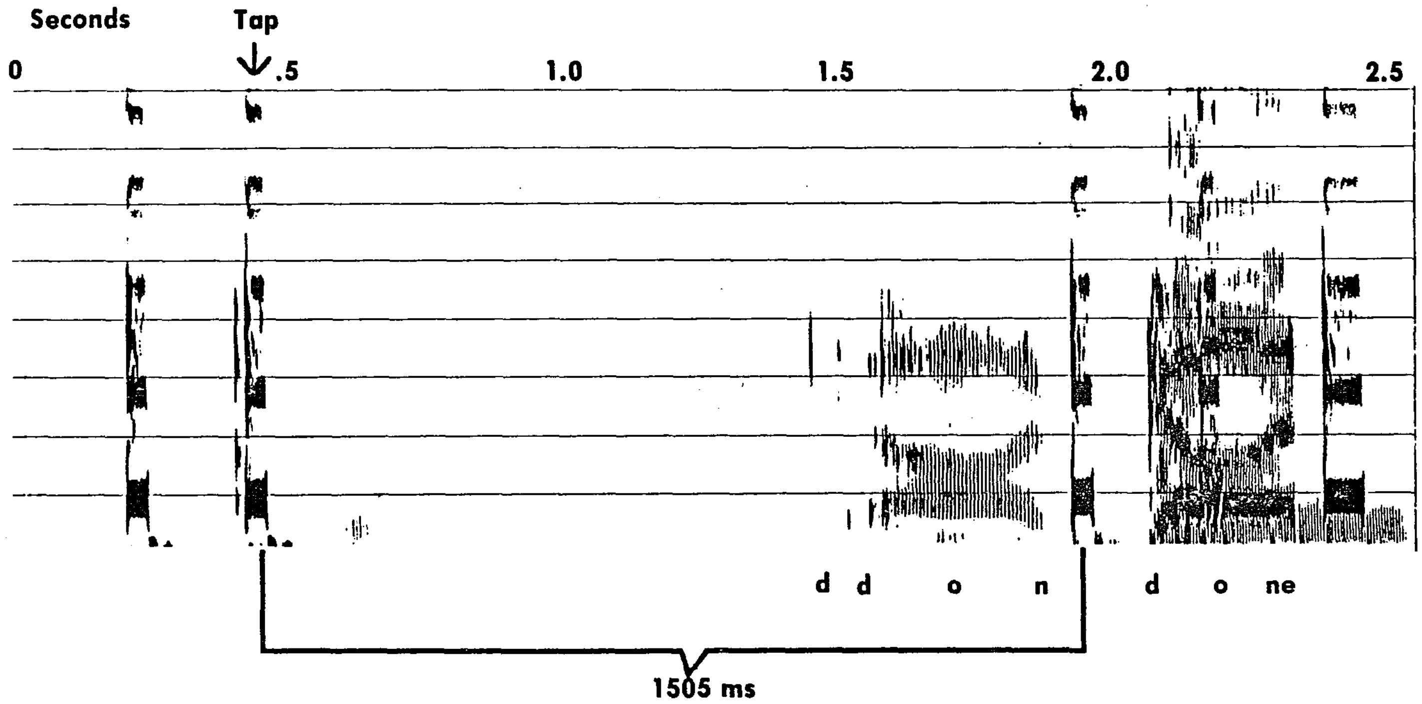


Figure 17. Spectrograph of subject saying, "d-d-on, done."

and then during the 1014 ms interval stumbled over the word "whose", repeating or extending "... ose..." before resuming speech and tapping.

Although the Fluency task was not examined in the analysis of variance, it was possible to examine speech output during long inter-tap intervals. Since the purpose of the task was to think of as many words as possible, the number of words initiated during these intervals was counted. Of the 24 trials examined (eight per subject), 17 or 71% had no words initiated, indicating that tapping was entrained by speech in this task too, although the effect may not have been as strong. Appendix E, Table 21 presents individual data on tapping intervals and speech output for this task.

Figure 17 is a spectrographic representation of one trial of the Fluency/Index task. During the 1505 ms interval, the subject is attempting to think of a word starting with "d". She pauses, says: "d - done" softly, and then more loudly, whereupon she starts tapping again.

General Discussion

Sex

Perhaps the most puzzling result of Experiment 2 was that the lateralized effects were due entirely to the females. In Experiment 1, sex was not an analyzed factor since there were more females than males. However, informal examination of the males' data in Experiment 1 shows no tendency towards less lateralization than the females.

The presence of bilateral effects in males but not females has no precedent in verbal-manual interference literature. A review of adult research using tapping tasks showed that where sex was a factor, it was not significant in the experimental condition (Lomas and Kimura, 1976; Lomas, 1980; Hellige and Longstreth, 1981). Two studies using dowel balancing found males to be more lateralized than females (Johnson and Kozma, 1977; and Lomas and Kimura, 1976).

We may note that males in Experiment 2 did not show greater left than right hand decrease in change indices over time as did females. However, probably more important were the very low levels of interference and high incidence of facilitation demonstrated by males. Kinsbourne and Hiscock (1983) suggest that the lower the level of interference, the more difficult it is to demonstrate lateralized differences. However, why such low levels of interference were found is no easier to explain than why there was no significant difference between right and left hand change indices.

One possible explanation for these results is that the bilateral effects shown by males actually represent greater lateralization of function. Work by Peters (1981) suggests the presence of a single system controlling the movements of both hands. His findings are consistent with Lomas and Kimura's (1976) notion of left hemisphere control of both hands for sequencing and placement. However, neither study found this unimanual control system to be sex related. Further research into sex effects might be enlightening.

It should also be noted that both studies recognized the need for explaining the abundant evidence for asymmetrical manual performance. Peters (1981) suggested that the higher level bimanual control system has better access to one hand than the other. Lomas and Kimura (1976) suggested similarly that the asymmetries occur at a lower level of programming: "at some point beyond the bilateral control exerted by the left hemisphere, i.e., at some point where the program of movements has already been transmitted to the left hand" (p.31). Therefore, even the concept of a lateralized system of control for both hands may not be sufficient for explaining the bilateral effects demonstrated by the males in this study.

Rhythmicity

Results of Experiment 2 were consistent with those of Experiment 1 in finding an overall hand effect due to greater right than left change indices (for output tasks) but no difference in degree of lateralization due to rhythmicity of the language task. The two possible interpretations of this result could again be cited as either a lack of sensitivity of the verbal-manual interference method to differences in degree of lateralization or acceptance of the result at face value, i.e. rhythmic output is not a predominantly left hemisphere property. This agrees with the Kelso et al. (1983) finding that rhythm is bilaterally represented. Unlike the rhyme versus category contrast tested in Experiment 1 which has a great deal of support in the literature for right hemisphere mediation of semantic language tasks (albeit from pathological populations), rhythm as a left hemisphere property is less well supported by previous studies. It would be easier in this case then to accept the second interpretation of the result: rhythmic output is not predominantly mediated by the left hemisphere.

Cognitive Demands

Although there were no lateralized language task results, there was a generalized language task effect. The fluency task caused greater interference with both tapping rate and tapping variability than the Prose or Nursery Rhyme tasks. This result is probably best interpreted as a reflection of cognitive difficulty. An examination of mean change indices and mean standard deviation of the interval between taps shows the least interference from the Nursery Rhyme task, somewhat greater interference from the Prose task, and the greatest interference from the Fluency task. This order of interference coincides with a subjective view of task difficulty. The Nursery Rhyme task, being the most automatized, required the least cognitive effort. The Prose task, although repetitious, appeared more difficult in that it required memorization of an unfamiliar passage, a task which was observed to be rather difficult for many subjects. This observation was supported by the fact that although both the Nursery Rhyme and Prose tasks had the same number of syllables, subjects recited the Prose passage fewer times per trial than the Nursery Rhyme passage. The Fluency task was the only task of the three in which the material was neither repetitious nor provided by the examiner; it required constant processing for output of new material.

A study by Hicks et al (1975) also supports the view that increased cognitive difficulty causes increased general interference. It was found that increased difficulty of a letter recall task caused a general increase in interference with no change in lateralized effects.

Effect of Tapping on Language Task

The significant hand task effect present in the analysis of speech rate decrements demonstrated that tapping does affect speech output. It was found that speech rate was significantly slower under the sequential tapping condition than under the index tapping condition. In fact, for the Nursery Rhyme and Prose tasks combined, there was a significant decrease from baseline speech rates during sequential tapping and a significant increase from baseline during index tapping. The Fluency task showed slower speech rates during sequential than index tapping but no significant increase or decrease from baseline rates. Since language task was held constant under both hand task conditions, the change in speech rates was clearly due to differences in the tapping task.

It is of note that this hand task effect was not lateralized. In other words, although the effect of speech on tapping rate was lateralized, the effect of tapping on speech was general. Most previous studies did not measure baseline and dual-task speech rates but those that did also found general effects of tapping on speech rate (Hiscock, 1982; Hiscock et al., 1983; Hiscock and Kinsbourne, 1978, 1980). Those studies which did find either lateralized effects of tapping on language task or no effects on language task were measuring errors on recall tasks rather than speech output (McFarland and Ashton, 1978a, 1978b; Bowers et al., 1978; Summers and Sharp, 1979).

Only Bowers et al. (1978) found no effect of tapping on a speech output task, the same Fluency task in fact as used in this study. The Bowers et al. (1978) result is not inconsistent with results of this study, however. Neither study found a significant decrement in speech rates from the baseline condition. However, since two different hand tasks were used in the present study, it was possible to demonstrate a change in speech rate output due to different hand task conditions.

Possible explanations for the differential effects of the two hand tasks on speech output and for the presence of bilateral rather than asymmetrical effects of tapping on language task might best be reserved for the following discussion of entrainment.

Entrainment

One possible interpretation for the decrease in speech rates seen during sequential tapping but not index tapping (for the Nursery Rhyme and Prose tasks) is that the functional similarity of sequential tapping and speech, as described previously by Lomas and Kimura (1976), caused the interference. However, this explanation does not account for the significant increase in speech rates occurring during index tapping. A more coherent explanation is that of entrainment. Recall that tapping rates were significantly slower for sequential tapping than for index tapping. It appears that speech rates became entrained to tapping rates: the slower sequential tapping rates caused slower speech rates, and the faster index tapping rates caused faster speech rates. This explanation would not be in conflict with the lack of interference or facilitation found on the Fluency task because it is not necessary to show significant changes from baseline, only slower speech rates during sequential tapping: a result which was also obtained for the Fluency task.

Entrainment may also account for why effects were general rather than lateralized. Although raw tapping rates were generally faster on the right hand than on the left, the difference between the two hands was not large. Mean tapping rates on the right and left hands differed by .42 taps per second whereas mean index and sequential tapping rates (which were associated with significant differences in speech rates) differed by 1.7 taps per second. If speech rate was driven by tapping rate, the hand difference in tapping rate may have been too small to produce a lateralized effect on speech output.

Hiscock (1982) came to similar conclusions about the relation between tapping rate and rate of verbal production in a study of task priority. Children in that study were instructed to emphasize tapping on some dual-task trials and to emphasize speaking on other trials. It was found that emphasizing tapping also increased speech output. No hand differences were demonstrated. Hiscock concluded that tapping rate set the pace for speaking rate and that the non-lateralized effects were due to similar left and right hand raw tapping rates.

A study by Wilke, Lansing, and Rogers (1975) also supports the above conclusions. The subject's task was to synchronize finger tapping to visual signals of various frequencies. It was found that breathing rate became entrained to tapping rate if the tapping rate did not vary too greatly from normal breathing rate. That the entrainment was due to the tapping and not to the visual stimuli was demonstrated when subjects monitored the visual stimuli without tapping. Under that condition, entrainment of breathing did not occur.

Studies by Kelso, et al. (1983) have also demonstrated that speech can be entrained by finger movements. Subjects were instructed to alternate long and short movements of the index finger while keeping the stress of speaking (repeating a one syllable word) constant. It was found that the change in movements affected speech output such that longer finger movements were associated with increased stress on word production.

The evidence cited thus far seems to indicate that the manual system drives the speech system. However, Kelso et al. (1983) found that when subjects were told to keep finger movements constant but to vary the stress of alternate syllables, finger movements followed the speech pattern: On stressed syllables, longer finger movements occurred, and on unstressed syllables, shorter finger movements occurred. Thus, Kelso et al. (1983) concluded that entrainment between speaking and manual performance is mutual.

Is there then evidence for entrainment of tapping to speech in the present study? It will be recalled that slowing down of tapping rate as indicated by unusually long inter-tap intervals was associated with slowing down of speech rate. Examination of the content of speech during those intervals suggests that it was the speech that slowed down the tapping. During a large percentage of the intervals, subjects were pausing because of clause boundaries, to correct errors, or in the case of the Fluency task, to think of a word. Often, an audible breath was heard during these long inter-tap intervals. In other words, there is evidence for a mutual interaction between the motor systems programming both speech and tapping, and as in the Kelso et al. (1983) studies, these interactions were not lateralized.

Another piece of evidence for the entrainment of tapping to speech output comes from the results of the variability analysis. The fact that the Fluency task caused the most variability in tapping rate may be partly a function of entrainment. Verbal output during the Fluency task was the most variable of all the language tasks (presumably due both to the difficulty of the task and to the single-word nature of the response). If pauses in speech give rise to pauses in tapping (as the analysis of the other language tasks suggests), the greater variability of pause length in speech during the Fluency task than during the other tasks would have resulted in greater tapping variability.

One purpose of this study was to determine if entrainment effects would be lateralized in the same way that interference effects are lateralized. As shown by evidence presented above, entrainment appears to be a general rather than a lateralized property of the motor system. Why this should be so may be revealed in an examination of the function served by entrainment.

Kelso, Holt, Rubin, and Kugler (1981) suggest that entrainment "ensures a stable resolution of simultaneous temporal processes throughout the whole system," (p. 251) and that it emerges as a consequence of systems' interactions as opposed to being "a priori prescriptions invested in a single cell (or program)" p. 256. Wilke et al. (1975) suggest that the central nervous system coordinates various neural events in order to "maximize precise and efficient integration of function" with the purpose of "minimizing total energy expenditure" (p. 348). In young children, concurrent vocalization (regardless of the semantic content of the words) has been shown to facilitate accuracy in the performing of a manual task (Tinsley and Waters, 1982).

Entrainment then seems to be a way of achieving maximum function within a limited capacity system. It emerges as a result of the interaction between two motor systems and does not seem to be a fixed property of a particular system (or hemisphere). The demonstration of mutual entrainment of finger movements and breathing, a non-lateralized process, is in line with the view of entrainment as a general process. Since we may be called upon to speak while performing manual activities with either or both hands, mutual entrainment between speech and only right-handed activity would be counter-productive. The purpose of achieving maximum efficiency would not be well-served if only left hemisphere activities functioned as mutually entrained systems.

Hand Task

The effect of hand task on speech output has already been noted: Speech output is faster during index tapping and slower during sequential tapping. Another significant hand task effect was seen in the variability analysis. Sequential tapping was found to be more variable than index tapping. This effect is probably due to physical differences between the two tasks. Subjects may have paused after each set of four taps before starting the sequence again. There could also be differences in the speed of each of the fingers. In fact, Sommers & Sharp (1979) measured the mean inter-tap interval for each finger position in a sequential tapping task and found a significant difference in length of interval as a function of position in sequence.

Of major interest to this study was whether sequential tapping would result in more lateralized interference than index tapping as Lomas and Kimura (1976) had found. In fact, Summers and Sharp (1979) found that index, not sequential, tapping resulted in lateralized interference. Furthermore, Kinsbourne and Hiscock (1983) point out that Lomas and Kimura's (1976) theory actually predicts bilateral interference with sequential tapping. If the left hemisphere is responsible for the control of all positioning or sequential movements, then interference within the left hemisphere from speaking should affect both right and left hand sequential tapping equally. As mentioned previously, Lomas and Kimura (1976) deal with this inconsistency by suggesting that the competition between speaking and tapping occurs at a lower level of programming.

This study found no significant differences in lateralization effects as a result of hand task and therefore supports the larger body of dual-task literature showing interference from a variety of manual tasks in adults and children (Kinsbourne and Cook, 1971; Hicks et al., 1975; Bowers et al., 1976; Hellige and Longstreth, 1981; Klingman and Sussman, 1983).

The one indication of difference in degree of laterality for the two hand tasks came from the baseline analysis of variance which showed right and left hand baseline index tapping rates to differ from each other more than right and left hand baseline sequential tapping rates differed from each other. In fact at 10 seconds, there was no significant difference between right and left hand baseline sequential tapping rates. From that baseline result it would not be unexpected to find less lateralized effects in the dual-task condition for sequential tapping since change indices are derived partly from baseline. However, as previously stated, hand task by hand was not significant. The following discussion of length of tapping trial may be more relevant in explaining Kimura's results.

Length of Trial

It was pointed out earlier that the index tapping portion of the study done by Lomas and Kimura (1976) used 10 second trials in contrast to the 30 second trial used by Bowers et al. (1978). During sequential tapping, Lomas and Kimura used a 15 second tapping trial. Experiment 2 found a hand effect at 20 and 30 seconds, and Experiment 1 found a hand effect at 15 seconds. However, at 10 seconds in Experiment 2, no differences between change indices for the two hands were found. It appears then, that the difference between tapping tasks in lateralization found by Lomas and Kimura (1976) was a function of the difference in the length of the tapping trial rather than in any inherent quality of the two tasks.

A ten second trial is apparently not sufficient to demonstrate lateralized differences. Examination of change indices over time shows that although the size of decrements decreased from ten to thirty seconds for both hands, there were greater decreases in interference on the left hand than the right hand over time. It appears that as the subject became more practiced at the task, there was less interference overall. However, the left hand adapted to the task to a larger degree than the right hand, resulting in greater differences between left and right hand change indices. McFarland and Geffen (1982) found similar results in a study that measured practice effects. Only left hand performance improved with practice in the dual-task condition. Perhaps initially both hemispheres were equally aroused but as task requirements became clear, the hemisphere that was least involved (the right) decreased its attention level, thereby reducing interference with the hand it programmed (the left).

Variability

Although results of the variability analysis have been mentioned previously, i.e. that sequential tapping was more variable than index tapping and that Fluency was more variable than the other language tasks, a major purpose of analyzing variability was to determine whether measures of variability in tapping rate would reveal lateralized hand differences in the same way that measures of reduction in tapping do. It was found that there were no lateralized differences when variability was measured. Both the hand task effect and the language task effect were bilateral.

Results of previous studies using variability to measure lateralized differences are less consistent than those using tapping rate decrements. McFarland and Ashton (1978a) found lateralized interference using variability measures but in that study, subjects were instructed to tap in unison to the beat of a metronome. In another study by McFarland and Ashton (1978b) where subjects did not tap to a beat, both rate and variability were measured. Similar lateralization effects were found for both measures except when the task was made more difficult, in which case variability measures showed bilateral interference. Hiscock et al. (1983) found results similar to those in this study in that tapping rate data showed lateralized interference but variability data did not. It appears then that variability in tapping rate is a less reliable measure of lateralized interference.

SUMMARY AND CONCLUSIONS

Although neither Experiment 1 nor Experiment 2 was able to differentiate between different degrees of laterality of various left-hemisphere mediated language tasks, both studies were consistent with the results of the large number of dual-task studies demonstrating greater disruption of right hand than left hand performance when a verbal output task and a manual task are carried out concomitantly. Whether this lack of differentiation between language tasks reflects brain organization or insensitivity of the technique employed is difficult to conclude. In any case, the general premise of the functional distance theory was left unchallenged by the above results.

One result which this theory cannot explain is the fact that although speech has been shown to produce asymmetric decrements in tapping rate, tapping has not been shown in this or other studies to produce asymmetric interference in speech output. Hiscock (1982) suggested as a possible interpretation for this finding that subjects "protect" speaking performance. Since the effect of tapping on speech is so minimal, no hand difference is produced. However, after finding that speech errors (on a tongue twister task) increased as speech rate increased in his task priority study, he had to conclude that subjects were not protecting speech performance at the expense of manual performance.

What emerges from Experiment 2 is the functioning of a different process, that of mutual entrainment, to account for the generalized effects of the speech-tapping interaction. It appears that at the same time that lateralized interference is causing aysmmetrical tapping rate decrements, the process of entrainment is affecting both speech and tapping output.

Hiscock et al. (1983) also concluded that entrainment effects are separable from lateralization effects. As in the present study, long pauses in tapping often co-occurred with pauses in speaking. When these long pauses between taps (above 500 ms) were omitted from the date analysis, asymmetrical decrements in tapping rate were still present, indicating that asymmetries were not a function of the entrainment between speech and tapping.

Entrainment differs from lateralized interference in several ways. First of all, entrainment is not a type of interference. Its effects may appear as either interfering or facilitatory: Thus, in the present study, speech rates were reduced by entrainment in some cases, but increased in others. Second, entrainment effects are bilateral whereas interference can be either lateralized or bilateral. So, at the same time as lateralized interference was affecting tapping, a generalized effect of mutual entrainment was operating, an effect independent of the lateralized tapping rate decrements. While Kinsbourne and Hicks (1978) state that "comparable" (p.347) motor programs (such as tapping the same rhythm with both hand and foot or humming and tapping the same rhythm) do not interfere with each other, their theory cannot explain how two concurrent tasks can both interfere and not interfere at the same time. Finally, unlike lateralized interference which appears to be unidirectional (that is, speech caused lateralized decrements in tapping but tapping did not cause lateralized decrements in speech) entrainment worked in both directions (speech became entrained with tapping and tapping became entrained with speech).

Another way of describing the above differences is to define lateralized interference as a structural effect and entrainment as a capacity effect. Structural effects result from competition between two tasks for the use of a particular sub-system within the brain, in this case the left hemisphere. Capacity effects, resulting from the diversion of attention from one task to another, may also be seen in terms of interference (Kinsbourne and Hiscock, 1983). However, Navon and Gopher (1979) in discussing the limitations of capacity models, point out that performance on one task does not necessarily deteriorate due to the presence of another task. Performance on one task may actually improve as performance on the second task improves. Such was the case for the effect of index tapping on speech rates: rapid tapping rates actually increased speech rates from baseline. As pointed out earlier, entrainment may be a way of maximizing capacity for greatest efficiency of function.

While uncovering the presence of these two kinds of effects (lateralized interference versus bilateral entrainment; or structual versus capacity effects) adds to the understanding of dual-task functioning, our knowledge of brain organization would be furthered significantly if a principle encompassing both systems could be formulated. Further research aimed at this goal might include more systematic study of the speech-tapping interaction. Both the rate of tapping and the rate of speaking could be manipulated experimentally to confirm the findings of entrainment in this study which were based on the inherent differences in index and sequential tapping rate, and on natural variations in speech rate. Since conclusions regarding the effect of speech on tapping were derived from analysis of only three subjects, this analysis should be repeated with a larger sample.

Examination of the interaction between tapping and language input tasks would clarify whether entrainment is purely a motor effect. Experiment 1 showed lateralized interference to be a motor effect, and although other studies dispute that result, motor effects seem to have predominated in the present studies. The only cognitive effect demonstrated was apparently due to task difficulty: the more difficult the language task, the greater the interference bilaterally. As mentioned earlier, the possibility that recall tasks engage motoric processes in long-term memory tasks should be studied further.

In summary, it can be said that both lateralized and general effects occurred when language and tapping tasks were performed concomitantly. Tapping rate was affected in both a lateralized and generalized manner. Overall there were greater right than left hand decrements in tapping rate (for output language tasks), an effect which was not dependent on the type of manual task but did require a sufficiently long tapping trial. At the same time, both right and left hand tapping rates were equally affected by the slowing down of speech rate due to clause boundaries and other factors. Speech output was affected only in a generalized manner such that for both hands, slower tapping rates caused slower speech rates, and faster tapping rates caused faster speech rates. Whereas the lateralized effects can be explained by Kinsbourne's functional distance principle, the presence of generalized mutual entrainment between speech and tapping points out the need for a more encompassing theory of the interaction between motor subsystems.

APPENDICES

Appendix A: Instrumentation

APPENDIX A

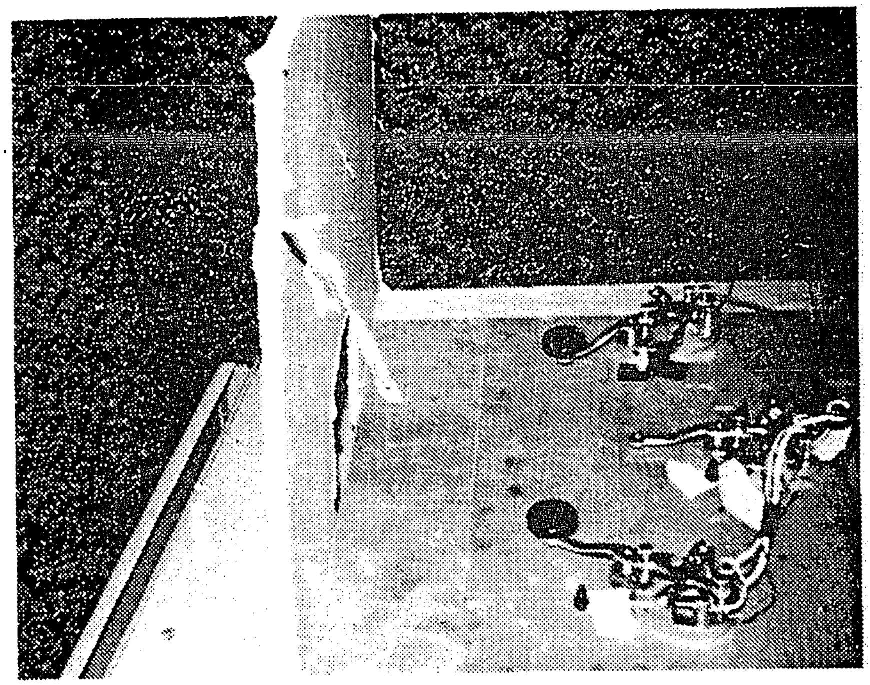


FIGURE 1. Experiment 1: Photograph of Test Apparatus.

APPENDIX A

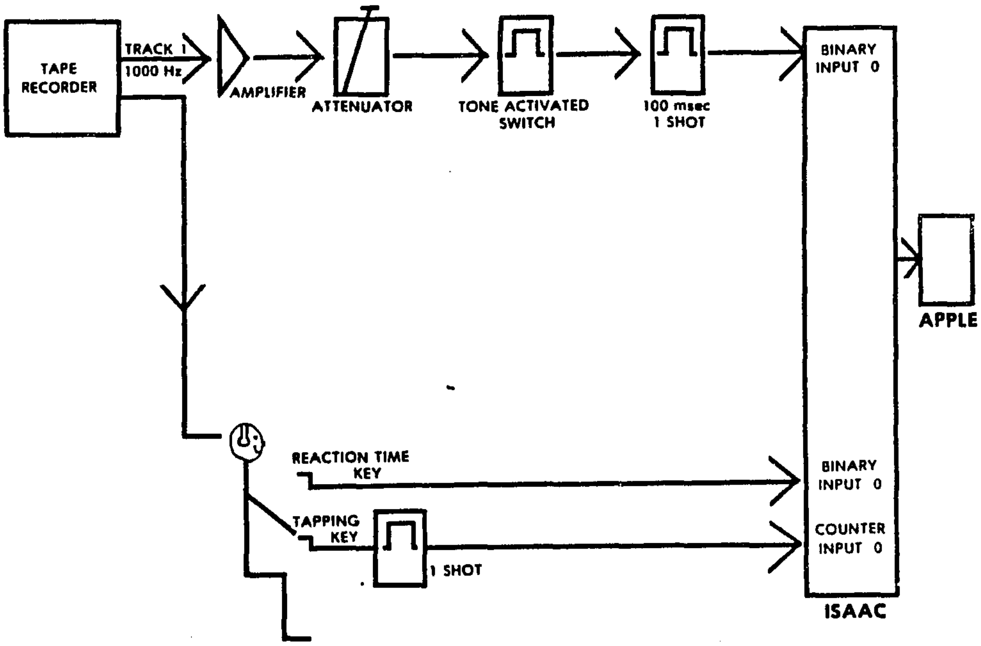
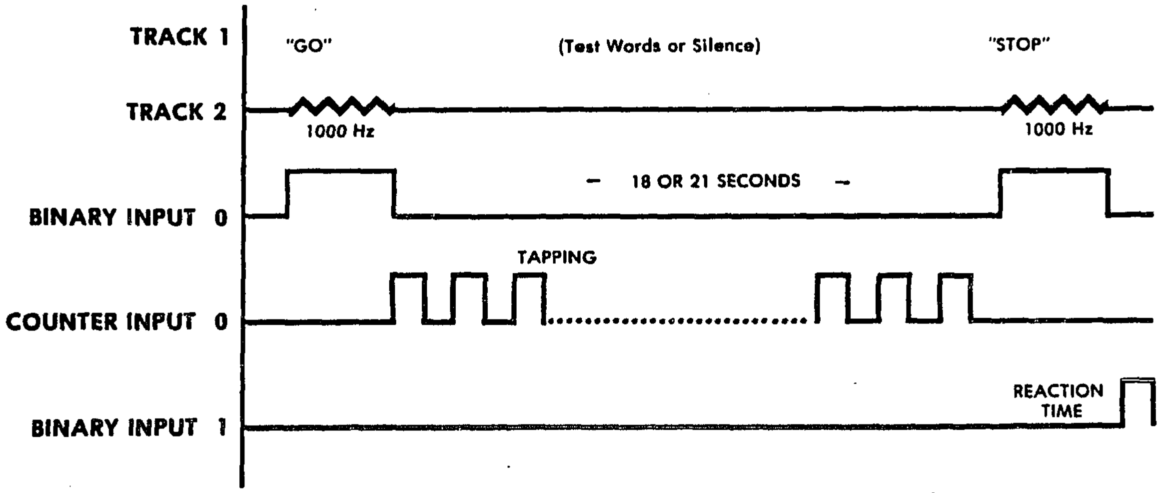


FIGURE 2. Experiment 1: Diagram of Test Set-Up.

APPENDIX A



1. The examiner turned on the tape recorder.

2. A 1000 Hz signal on track 2 of the tape activated a tone-activated switch.

3. After suitable conditioning, the tone was passed to ISAAC's binary input #0 which started the timing cycle and then cleared the counter.

4. At the same time, subjects heard "go" on track 1 of the tape signaling them to start tapping (and speaking or listening).

5. After suitable conditioning, to prevent multiple counts from "switch bounce", the tapping key supplied input to ISAAC's counter input #0.

6. After 18 or 21 seconds, a second 1000 Hz tone on track 2 of the tape was passed to binary input #0, stopping the timing cycle and initiating reading and recording of the number of taps by the counter.

7. Concommitant with the second one was the word "stop" or the target word which signaled subjects to stop tapping and hit the reaction time key.

8. A second timing cycle was started in order to read reaction time. The reaction time key was connected directly to ISAAC's binary input #1 which recorded the elapsed time from the target word to the subject's response.

FIGURE 3. Experiment 1: Diagram of Test Procedure.

APPENDIX A

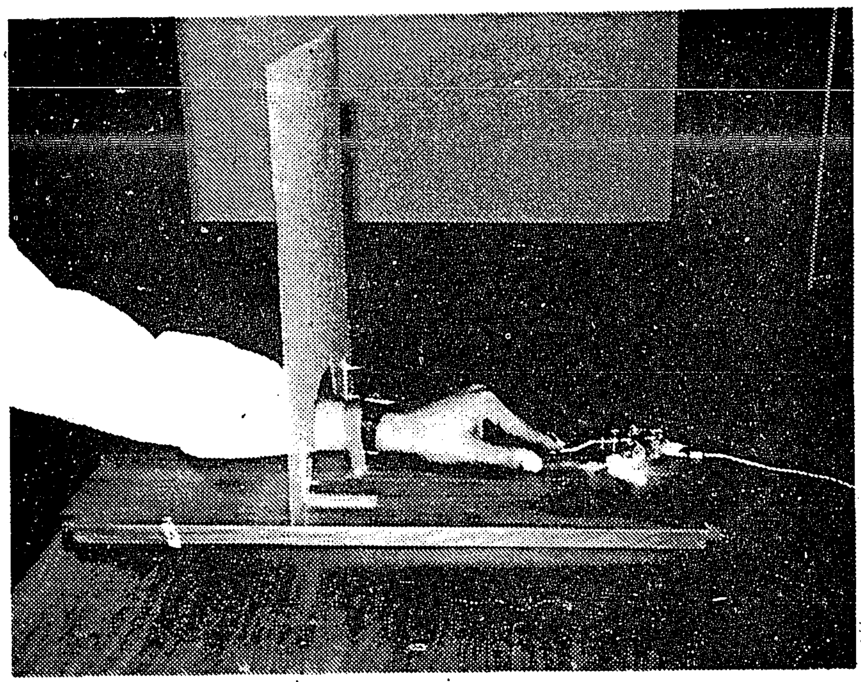


FIGURE 4. Experiment 2: Photograph of Test Apparatus.

APPENDIX A

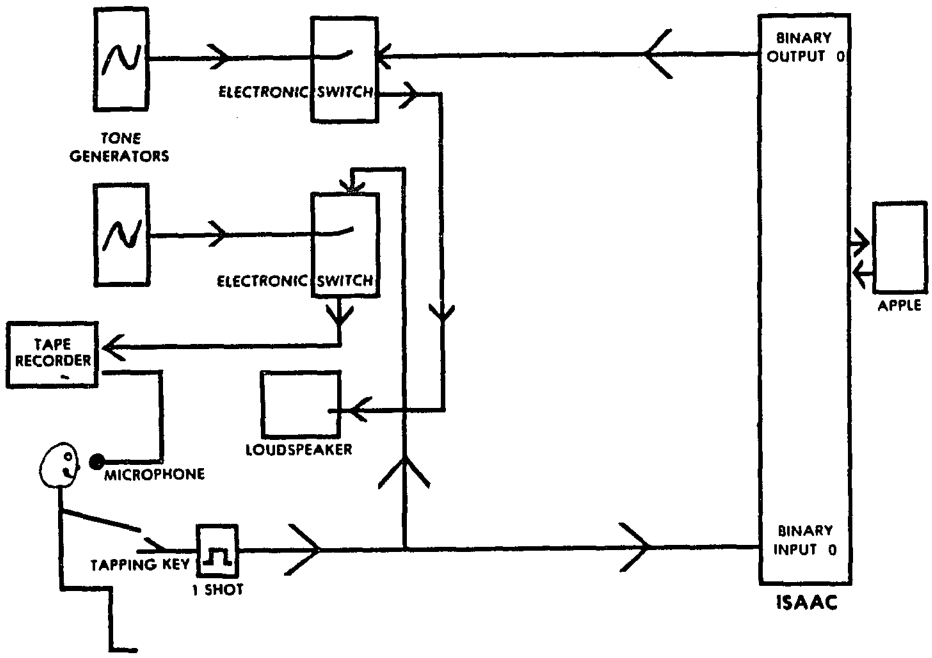
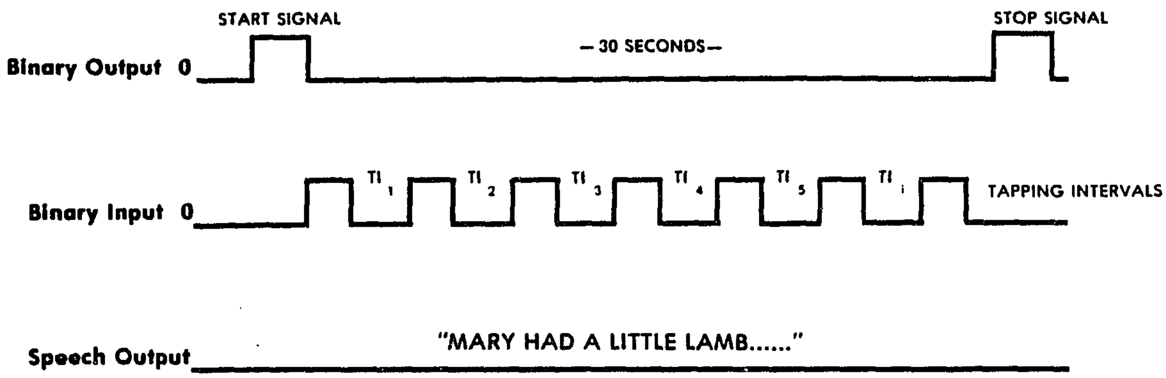


FIGURE 5. Experiment 2: Diagram of Test Set-Up.

APPENDIX A



1. The examiner turned on the tape recorder.

2. The examiner hit the space bar on the computer to begin data collection.

3. ISAAC's binary output #0 generated a "start" signal (1 beep) heard by the subject.

4. The subject started tapping and/or speaking.

5. ISAAC's binary input #0 recorded each tapping interval and the total elapsed time.

6. After 30 seconds elapsed time, ISAAC's binary output #0 generated a "stop" signal (1 beep).

7. A complete record of tapping intervals was saved digitally on one disk. In addition the taps were used to trigger brief tone bursts which were recorded on one track of an audio tape. Speech ouput was recorded on the other track.

FIGURE 6. Experiment 2: Diagram of Test Procedure.

Appendix B: Computer Programs

COMPUTER PROGRAM: Experiment 1.

```
1  PR# 0
10  HOME
20  VTAB 10
30  PRINT "   * WELCOME TO TAPPING
     *
40  PRINT : PRINT : PRINT
50  DIM X%(3,24)
60 N = 0
70  & PAUSE = 1
100  HOME : VTAB 5
110  PRINT "         * MENU *": PRINT
     : PRINT
120  PRINT "1: INSTRUCTIONS
130  PRINT "2: COLLECT DATA
140  PRINT "3: DISPLAY DATA
200  GET A$
210 X =  VAL (A$)
220  IF X < 1 OR X > 3 THEN  GOTO
     200
230  ON X GOTO 2000,1000,3000
1000 N = 0
1005  HOME : VTAB 10: PRINT "  GI
     VE INSTRUCTIONS TO SUBJECT":
      PRINT : PRINT "'SPACE TO CO
     NTINUE": GET A$
1010  HOME : VTAB 10
1065 N = N + 1
1067  PRINT "THIS IS TRIAL #";N
1068  PRINT "RIGHT HAND OR LEFT H
     AND (R/L)?  ";
1070  GET A$
1080  IF A$ = "R" GOTO 1110
1090  IF A$ = "L" GOTO 1120
1100  GOTO 1070
1110 H = 1
1115  PRINT "RIGHT": GOTO 1130
1120 H = 2
1125  PRINT "LEFT": GOTO 1130
1130  PRINT : PRINT : PRINT "STAR
     T TAPE RECORDER"
1135 C = 0
1140  & BIN,(TV) = X,(XM) = 65532

1150  IF X / 2 -  INT (X / 2) = 0
      THEN  GOTO 1140
1153  & PAUSE = .2
1154  HOME
```

```
1157  & CLRCOUNTER,(C#) = Ø
1160  & CLRTIMER
1170  & BIN,(TV) = X,(XM) = 65532
1200  IF  INT (X / 2) > Ø THEN  GOTO
     18ØØ
1210  IF X / 2 -  INT (X / 2) = Ø
      THEN  GOTO 117Ø
1220  & COUNTERIN,(TV) = C
1250  & TIMERIN,(TV) = T1%
1255 T1% = T1% - 5Ø
1260  & CLRTIMER
1263  & TIMERIN,(TV) = T2%
1264 T2% = T2% - 5Ø
1265  IF T2% > 5ØØØ THEN  GOTO 16
     ØØ
1270  & BIN,(TV) = X,(XM) = 65532

1280  IF  INT (X / 2) = Ø THEN  GOTO
     1263
1290  & TIMERIN,(TV) = T2%
1500 X%(1,N) = H
1510 X%(2,N) = C / T1% * 1ØØØØØ
1520 X%(3,N) =  INT (T2%)
1530  PRINT "TRIAL #";N;
1540  IF H = 1 THEN  PRINT " RIGH
     T"
1550  IF H = 2 THEN  PRINT " LEFT
     "
1560  PRINT "TAPPING RATE = ";X%(
     2,N) / 1ØØ;" TAPS/SEC
1570  PRINT "REACTION TIME= ";X%(
     3,N);" MSEC"
1575  IF N > 23 THEN  GOTO 3ØØØ
1580  PRINT "NEXT TRIAL, REPEAT,
     OR EXIT (N/R/E) ": GET A$
1582  IF A$ = "E" THEN  GOTO 3ØØØ

1584  IF A$ = "N" THEN  GOTO 1Ø1Ø

1585  IF A$ = "R" THEN  GOTO 17ØØ

1586  GOTO 158Ø
1600  PRINT "TARGET WORD MISSED":
      GOTO 15ØØ
1700 N = N - 1: GOTO 1Ø1Ø
1800  PRINT : PRINT "SUBJECT HIT
     THUMB BUTTON PREMATURELY": PRINT
     : PRINT "'SPACE' TO CONTINUE
     ": GET A$:N = N - 1: GOTO 1Ø
     1Ø
```

```
2000  HOME
2005 X = Ø
2010  PRINT "CHANNEL 2 OF TAPE RE
     CORDER TO 1 WATT COLBOURNE A
     MP": GOTO 29ØØ
2015  PRINT "CONNECT 'GATE' OF CO
     LBOURNE AMPLIFIER TO GROUND"
     : GOTO 29ØØ
2020  PRINT "COLBOURNE AMP TO 1Ø
     OHM ATTENUATOR": GOTO 29ØØ
2025  PRINT "CONNECT ISAAC'S 5V T
     O '+5 VOLT POWER' ON COMPUTE
     R OUTPUT MODULE (S62-Ø6). AL
     SO CONNECT ISAAC'S GND TO TH
     E GROUND ON THE COMPUTER OUP
     UT MODULE.": GOTO 29ØØ
2030  PRINT "SET ATTENUATOR TO '8
     ' AND CONNECT TO MIC INPUT O
     F VOICE SWITCH ": GOTO 29ØØ
2040  PRINT "CONNECT'Ø OUT' OF VO
     ICE SWITCH TO 'T' INPUT OF 1
     ØØ SEC TIMER (GS 1216A). SET
      TIMER TO 'NORMAL' AND TIME
     TO 1ØØ MS.": GOTO 29ØØ
2045  PRINT "CONNECT 'REVERSE Z'
     OUTPUT OF 1ØØ SEC TIMER TO A
      '-12 VOLTS' ON THE COMPUTER
      OUTPUT MODULE AND THE CORRE
     SPONDING '+5 VOLTS' TO ISAAC
     'S BINARY INPUT#Ø.": GOTO 29
     ØØ
2050  PRINT "CONNECT SNAP TERMINA
     LS OF BUTTON BOX TO 'GND' AN
     D 'NO/NC' OF GRASON STADLER
     INPUT CONVERTER (MODEL 1211)
     . SWITCH INPUT CONVERTER TO
     'NO'": PRINT
2055  GOTO 29ØØ
2060  PRINT "CONNECT 'T' OUTPUT O
     F INPUT CONVERTER TO 'T' INP
     UT OF 1ØØ SEC TIMER (MODEL 1
     216A). SET TIMER TO 2Ø MS AN
     D 'OPERATE-RESET.": GOTO 29Ø
     Ø
```

```
2070  PRINT "CONNECT 'Z' OUTPUT O
     F 100 SEC TIMER TO A '-12 VO
     LTS' OF COMPUTER OUTPUT MDUL
     E AND THE CORRESPONDING '+5
     VOLTS TO ISAAC'S COUNTER INP
     UT (CNT) #0": GOTO 2900
2080  PRINT "CONNECT 'THUMB' OF B
     UTTON BOX TO A '-12 VOLTS' O
     F COMPUTER OUTPUT MODULE AND
      THE CORRESPONDING '+5 VOLTS
     ' TO ISAAC'S BINARY INPUT #1
     ": GOTO 2900
2900  PRINT : PRINT : PRINT : PRINT
     "SPACE TO CONTINUE": GET A$
2910 X = X + 1
2915  HOME
2920  ON X GOTO 2015,2020,2025,20
     30,2040,2045,2050,2060,2070,
     2080,100
3000  HOME : PRINT "RIGHT","TAPS/
     S","RT(MS)"
3001  IF N > 24 THEN N = 24: PRINT
     "YOU HAD MORE THAN 24 TRIALS
     "
3002 H = 1
3005  GOSUB 3300
3010  FOR X = 1 TO N
3020  IF X%(1,X) <  > H THEN  GOTO
     3210
3030  PRINT X;":",X%(2,X) / 100,
3032  IF X%(2,X) = 0 THEN  GOTO 3
     075
3035 Y(1) = Y(1) + 1
3060 Y(3) = Y(3) + X%(2,X)
3070 Y(4) = Y(4) + X%(2,X) ^ 2
3075  IF X%(3,X) > 5000 THEN  GOTO
     3110
3080 Y(5) = Y(5) + X%(3,X)
3090 Y(6) = Y(6) + X%(3,X) ^ 2
3100  GOTO 3200
3110 Y(2) = Y(2) + 1
3120  PRINT "MISS"
3130  GOTO 3210
3200  PRINT X%(3,X)
```

```
3210  NEXT X
3220  PRINT "-------------------
     ----------------
3230  PRINT "TRIALS:",Y(1),Y(1) -
     Y(2)
3235  PRINT "MISSES:"," ",Y(2)
3237  ONERR  GOTO 3247
3240  PRINT "MEAN",:M1 = Y(3) / Y
     (1) / 100:M2 = Y(5) / (Y(1) -
     Y(2))
3245  PRINT  INT (1000 * M1) / 10
     00, INT (10 * M2) / 10
3247  ONERR  GOTO 3257
3250  PRINT "ST.DV:",:S1 =  SQR (
     (Y(4) - Y(3) ^ 2 / Y(1)) / (
     Y(1) - 1)) / 100:S2 =  SQR (
     (Y(6) - Y(5) ^ 2 / (Y(1) - Y
     (2))) / (Y(1) - Y(2) - 1))
3255  PRINT  INT (S1 * 1000) / 10
     00, INT (S2)
3257  PR# 1: PRINT  CHR$ (9);"A":
      PRINT  CHR$ (9);"S"
3258  PR# 0
3260  PRINT : PRINT "SPACE TO CON
     TINUE": GET A$
3270  IF H = 2 THEN  GOTO 100
3280 H = 2: HOME : PRINT "LEFT","
     TAPS/S","RT(MS)
3290  GOTO 3005
3300  FOR X = 1 TO 6
3310 Y(X) = 0
3320  NEXT X
3330  RETURN
3400 Y(X) = 0
```

COMPUTER PROGRAM: Experiment 2.

```
10  REM  TAP DANCE FEB 1983
20  LOMEM: 16384
100  HOME : & BOUT,(DV) = 0
200  DIM I%(300,8):X = 1:ET = 0:C
     = 9:MX = 30:N = 0
210  DIM RA(300)
220 ZZ% = 0
230  DIM XX(33)
500  HOME : PRINT "   * MENU *": PRINT

510  PRINT "1: RUN SUBJECT"
520  PRINT "2: CHANGE SAMPLING TI
     ME FROM ";MX;" SEC."
530  PRINT "3: SHOW DATA ON SCREE
     N"
540  PRINT "4: GRAPH DATA"
550  PRINT "5: PRINT DATA"
560  PRINT "6: STATISTICS CALCULA
     TIONS"
570  PRINT "7: SAVE DATA ON DISK"

580  PRINT "8: RECALL DATA FROM D
     ISK"
590  PRINT "9: REPEAT SINGLE TRIA
     L"
600  GET A$: IF A$ < "1" OR A$ >
     "9" THEN  GOTO 600
610 X =  VAL (A$)
620  ON X GOTO 1000,2000,3000,400
     0,5000,6000,7000,8000,9000
1000  HOME :ZZ% = 1: INPUT "SUBJE
      CT NAME? ";NM$
1001  PR# 1: PRINT "SUBJECT: ";NM
      $;"  RAW DATA": PRINT : PR#
      0
1010  PRINT "IS THIS A TAPPING TR
      IAL? (Y/N)"
1020  GET A$: IF A$ = "Y" THEN  GOTO
      1050
1030  IF A$ = "N" THEN  GOTO 1500

1040  GOTO 1020
1050 Y = 1
1060  GOSUB 12000
1070  HOME
1080  IF Y = 8 THEN  GOTO 1200
1090  PRINT "N:NEXT TAPPING TRIAL
```

```
1100  PRINT "R:REPEAT LAST TRIAL
1110  PRINT "M:MENU
1115  PRINT "S:SPEECH ONLY"
1120  GET A$
1130  IF A$ = "M" THEN  GOTO 1170

1140  IF A$ = "N" THEN  GOTO 1180

1150  IF A$ = "R" THEN  GOTO 1190

1155  IF A$ = "S" THEN  GOTO 1500

1160  GOTO 1120
1170 ZZ% = 1:TR% = Y: GOTO 500
1180 Y = Y + 1: GOTO 1060
1190  GOTO 1060
1200  HOME : PRINT "DATA MUST BE
     SAVED ON DISK"
1205 TR% = 8
1210  PRINT : PRINT " 'SPACE' FOR
      MENU": GET A$: GOTO 500
1500  GOSUB 13000
1510  GOTO 1070
2000  HOME : PRINT "CURRENT SAMPL
     ING TIME=";MX;"SEC"
2010  PRINT : INPUT "NEW SAMPLING
      TIME? ";MX
2020  PRINT : PRINT "MAXIMUM EVEN
     T RATE=";300 / MX;"EVENTS PE
     R SEC"
2030  PRINT : PRINT "SPACE FOR ME
     NU": GET A$: GOTO 500
3000  HOME : REM  SHOW ON SCREEN
     AND EDIT
3005  IF ZZ% = 0 THEN  GOTO 11000

3010  PRINT "WHICH TRIAL #"
3020  GET A$: IF A$ > "8" OR A$ <
     "1" THEN  GOTO 3020
3030 Y =  VAL (A$)
3040  IF N(Y) = 0 THEN  GOTO 3600

3060 A = 1
3065  HOME : PRINT "TRIAL #:";Y;"
        HAND:";HN$(Y);"     TASK:"
     ;TS$(Y);"   N:";N(Y)
3070  FOR X = A TO A + 35
3080  IF X > N(Y) THEN  GOTO 3110
```

```
3090  PRINT X;":";I%(X,Y),
3100  NEXT X
3110  PRINT : PRINT "CONTINUE/NEW
      TRIAL/EDIT/MENU (C/N/E/M)
3120  GET A$
3130  IF A$ = "C" THEN  GOTO 3170

3140  IF A$ = "N" THEN  GOTO 3000

3150  IF A$ = "E" THEN  GOTO 3300

3160  IF A$ = "M" THEN  GOTO 500
3165  GOTO 3120
3170 A = A + 36
3180  IF A + 36 > N(Y) THEN A = N
     (Y) - 35
3185  IF A < 1 THEN A = 1
3190  GOTO 3065
3300  INPUT "WHICH EVENT?";X
3310  PRINT "INTERVAL:";I%(X,Y);"
     MS"
3320  INPUT "HOW MANY INTERVALS S
     HOULD THIS REPRESENT?";N
3330 N(Y) = N(Y) + N - 1: IF N(Y)
      > 300 THEN N(Y) = 300
3340  FOR C = N(Y) TO X + N STEP
      - 1
3350 I%(C,Y) = I%(C - N + 1,Y)
3360  NEXT C
3370 I%(X,Y) = I%(X,Y) / N
3380  FOR C = X + 1 TO X + N - 1
3390 I%(C,Y) = I%(X,Y)
3400  NEXT C
3500  GOTO 3065
3600  PRINT "NO DATA FOR THIS TRI
     AL"
3610  PRINT "NEW TRIAL/MENU?(N/M)
     "
3620  GET A$
3630  IF A$ = "M" THEN  GOTO 500
3640  IF A$ = "N" THEN  GOTO 3000

3650  GOTO 3620
4000  HOME
4005  IF ZZ% = 0 THEN  GOTO 11000

4010  HGR : HCOLOR= 7
4020  & ALTSET
4025  HCOLOR= 7
```

```
4027  & PLTFMT = 7
4030  & OUTLINE
4040  HOME : VTAB 21
4050  PRINT "WHICH TRIAL#?"
4060  GET A$: IF A$ > "8" OR A$ <
     "1" THEN  GOTO 4060
4070 Y =  VAL (A$)
4080  FOR X = 2 TO 2 * N(Y)
4085 PL% = I%(X / 2,Y) / 5: IF PL
     % > 127 THEN PL% = 127
4087  HCOLOR= 7
4090  & NXTPLT = PL%
4100  NEXT X
4110  HOME : VTAB 21
4120  PRINT "NEW TRIAL/MENU/PRINT
     OUT (N/M/P)?"
4130  GET A$
4140  IF A$ = "N" THEN  GOTO 4020

4150  IF A$ = "M" THEN  GOTO 4170

4155  IF A$ = "P" THEN  GOTO 4200

4160  GOTO 4130
4170  TEXT : GOTO 500
4200  PRINT "RAW DATA/EDITTED DAT
     A (R/E)?"
4205  GET A$
4210  IF A$ = "R" OR A$ = "E" THEN
      GOTO 4230
4220  GOTO 4205
4230  PR# 1
4240  PRINT  CHR$ (9);"G"
4242  PRINT NM$;"#";A$;"  TRIAL#
     ";Y;" ";HN$(Y);"  ";TS$(Y)
4250  PR# 0
4260  GOTO 4110
5000  HOME
5005  IF ZZ% = 0 THEN  GOTO 11000

5020  & DAY TO YR,MO,DT,DA
5025  PR# 1
5030  PRINT MO;"/";DT;"/";YR
5040  PRINT NM$
5045 Y = 0
5050 Y = Y + 1: IF Y > TR% THEN  GOTO
     5130
5055 ET = 0
5057  PRINT "TRIAL #";Y;"    ";
5060  PRINT HN$(Y);" ";TS$(Y): PRINT
```

```
5070  PRINT "EVENT:";"INTERVAL:";
     "TIME": PRINT
5080  FOR X = 1 TO N(Y)
5085 ET = ET + I%(X,Y)
5090  PRINT X;":";I%(X,Y);":";ET,

5100  NEXT X
5110  PRINT : PRINT "MEAN INTERVA
     L="; INT (ET / N(Y) * 100) /
     100;" MS"
5120  PRINT : PRINT
5125  GOTO 5050
5130  PR# 0
5140  GOTO 500
6000  HOME : REM  STATISTICS
6010  IF ZZ% = 0 THEN  GOTO 11000

6100  HOME
6110  PRINT "STATISTICS FOR SINGL
     E TRIAL": PRINT
6120  PRINT "STATISTICS FOR ALL T
     RIALS": PRINT
6130  PRINT "RETURN TO MENU": PRINT

6140  PRINT "(S/A/M)"
6150  GET A$
6160  IF A$ = "S" THEN  GOTO 6200

6170  IF A$ = "A" THEN  GOTO 6300

6180  IF A$ = "M" THEN  GOTO 500
6190  GOTO 6150
6200  HOME : PRINT "WHICH TRIAL#?
     "
6210  GET A$: IF A$ > "8" OR A$ <
     "1" THEN  GOTO 6220
6220 Y =  VAL (A$)
6225  GOSUB 6900
6230  GOSUB 6500
6240  GOTO 6100
6300  GOSUB 6900
6305  FOR Y = 1 TO 8
6310  GOSUB 6500
6320  NEXT Y
6330  GOTO 500
6500  HOME : PR# 1
6510  PRINT NM$;"   DURATION FOR
     EACH BLOCK=";D%;" SECS"
```

```
6520  PRINT Y,HN$(Y),TS$(Y)
6530 C = 1:ET = 0:X = 1
6540  GOSUB 6970
6550  FOR X = 1 TO N(Y)
6560 ET = ET + I%(X,Y)
6570  IF ET >  = (C - 1) * D% * 1
     000 THEN  GOSUB 6970
6580  NEXT X
6590 XX(C) = X - 1
6600  IF XX(C) - XX(C - 1) < 2 THEN
     C = C - 1
6610 XX(0) = C
6620  FOR C = 1 TO XX(0) - 1
6630 S = 0:SQ = 0:N = 0
6640  FOR X = XX(C) TO XX(C + 1)
6650 N = N + 1
6660 S = S + I%(X,Y)
6670 SQ = SQ + I%(X,Y) ^ 2
6680  NEXT X
6690  IF N < 2 THEN  GOTO 6760
6700 M = S / N:SD =  SQR ((SQ - S
      ^ 2 / N) / (N - 1)):SE = SD
      /  SQR (N)
6705  PRINT "BLOCK #:",C
6710  PRINT "NO. OF EVENTS:",N
6720  PRINT "MEAN INTERVAL:", INT
     (M * 100) / 100
6730  PRINT "STD. DEVIATION:", INT
     (SD * 100) / 100
6740  PRINT "STD. ERROR:", INT (S
     E * 100) / 100
6750  PRINT : PRINT
6760  NEXT C
6765  PR# 0
6770  RETURN
6900  HOME
6910  PRINT "OVER  WHAT LENGTH OF
      TIME DO YOU WISH EACH AVERA
     GE TO BE CALCULATED?"
6920  PRINT "(MAX =    ";MX;" SECS
           MIN=1 SEC)": PRINT
6930  INPUT "GIVE TIME IN SECS
     ";D%
6940  IF D% > MX OR D% < 1 THEN  GOTO
     6930
6950  RETURN
6970 XX(C) = X
6980 C = C + 1
6990  RETURN
```

```
7000  HOME
7005  IF ZZ% = 0 THEN  GOTO 11000

7010  PRINT "   SAVE ON DISK   ":
      PRINT
7020  PRINT "MAKE SURE DISK IS IN
      PLACE": PRINT
7050  PRINT : INPUT "BLOCK? ";D$
7060 ND$ = NM$ + "-" + D$
7080 D$ =  CHR$ (13) +  CHR$ (4)
7090  PRINT D$;"OPEN";ND$
7100  PRINT D$;"WRITE";ND$
7105  PRINT NM$: PRINT TR%
7110  FOR Y = 1 TO TR%
7120  PRINT HN$(Y)
7122  PRINT TS$(Y)
7124  PRINT N(Y)
7130  FOR X = 1 TO N(Y)
7140  PRINT I%(X,Y)
7150  NEXT X
7160  NEXT Y
7165  PRINT
7170  PRINT D$;"CLOSE";ND$
7180  GOTO 500
8000  HOME
8005  IF ZZ% = 1 THEN  GOTO 11100

8010  PRINT "   RECALL FROM DISK"
     : PRINT
8020  PRINT "MAKE SURE DISK IS IN
      PLACE": PRINT
8030  PRINT "NAME OF DATASET IN F
     OLLOWING FORMAT?": PRINT
8040  PRINT "---> NAME-BLOCK#"
8045  PRINT
8047  INPUT "---> ";ND$
8050 D$ =  CHR$ (13) +  CHR$ (4)
8055  PRINT
8060  PRINT D$;"OPEN";ND$
8070  PRINT D$;"READ";ND$
8075  INPUT NM$: INPUT TR%
8080  FOR Y = 1 TO TR%
8090  INPUT HN$(Y),TS$(Y),N(Y)
8100  FOR X = 1 TO N(Y)
8110  INPUT I%(X,Y)
8120  NEXT X
8130  NEXT Y
8140  PRINT D$;"CLOSE";ND$
8145 ZZ% = 1
8150  GOTO 500
```

```
9000  HOME : REM  SINGLE TRIAL
9100  PRINT "GIVE TRIAL #";
9110  PRINT : GET A$: IF A$ < "1"
      OR A$ > "8" THEN  GOTO 9110

9120 Y =  VAL (A$)
9130  GOSUB 12000
9140  GOTO 500
10000  PRINT "OPTION NOT YET AVAI
     LABLE": FOR X = 1 TO 1000: NEXT
     X: GOTO 500
11000  HOME
11010  PRINT "LOAD OR COLLECT DAT
     A FIRST"
11020  & PAUSE = 1
11030  GOTO 500
11100  HOME : PRINT "TO ERASE EXI
     STING DATA SET TYPE 'RUN' AN
     D START OVER"
11110  END
12000  HOME : INPUT "HAND? ";HN$(
     Y): IF HN$(Y) = "" THEN HN$(
     Y) = "*"
12010  HOME : INPUT "TASK? ";TS$(
     Y): IF TS$(Y) = "" THEN TS$(
     Y) = "*"
12020 X = 0:ET = 0
12030  HOME : PRINT "HIT SPACE BA
     R TO START SAMPLING": GET A$
     : HOME
12040  & BOUT,(DV) = 1: & PAUSE =
     .5: & BOUT,(DV) = 0
12050  & LOOK FOR BIN,(XM) = 6553
     5,(TV) = EV,(TH) = 1: & TIME
     RIN,(TV) = T: & CLRTIMER
12060  & LOOK FOR BIN,(XM) = 6553
     5,(TV) = EV,(TH) = 1: & TIME
     RIN,(TV) = T: & CLRTIMER
12070 I%(X,Y) = T + C:ET = ET + T
     :X = X + 1: IF ET > 1000 * M
     X OR X > 300 THEN  GOTO 1209
     0
12080  GOTO 12060
12090 N(Y) = X - 1: & BOUT,(DV) =
     1: & PAUSE = .5: & BOUT,(DV)
      = 0
```

```
12100  PR# 1
12110  PRINT "TRIAL#";Y
12120  PRINT "HAND:";HN$(Y);"   TA
     SK:";TS$(Y)
12130  FOR X = 1 TO N(Y): PRINT I
     %(X,Y);" ";: NEXT X: PRINT
12140  PR# 0
12150  RETURN
13000  REM  SPEECH ONLY TIMER
13030  HOME : PRINT "HIT SPACE BA
     R TO START TIMING": GET A$: HOME

13040  & BOUT,(DV) = 1: & PAUSE =
     .5: & BOUT,(DV) = 0
13050  & CLRTIMER
13055  & TIMERIN,(TV) = T: IF T <
     MX * 500 THEN  GOTO 13055
13060  & CLRTIMER
13070  & TIMERIN,(TV) = T: IF T <
     MX * 500 THEN  GOTO 13070
13090  & BOUT,(DV) = 1: & PAUSE =
     .5: & BOUT,(DV) = 0
13100  RETURN
```

COMPUTER PROGRAM: Experiment 2 — Histogram.

```
10  REM   HISTOGRAM FEB 1984
20  LOMEM: 16384
100  HOME : & BOUT,(DV) = Ø
200  DIM I%(3ØØ,8):X = 1:ET = Ø:C
      = 9:MX = 3Ø:N = Ø
21Ø  DIM RA(3ØØ)
215  DIM H%(17)
22Ø ZZ% = Ø
23Ø  DIM XX(33)
255  VTAB 21: PRINT "     ";: FOR
     H = 1 TO 8: PRINT H;"    ";: NEXT
     H: PRINT "*1ØØ MSEC"
5ØØ  HOME : PRINT "    * MENU *": PRINT

54Ø  PRINT "4: GRAPH DATA"
58Ø  PRINT "8: RECALL DATA FROM D
     ISK"
6ØØ  GET A$: IF A$ < "1" OR A$ >
     "9" THEN  GOTO 6ØØ
61Ø X =  VAL (A$)
62Ø  ON X GOTO 1ØØØ,2ØØØ,3ØØØ,4ØØ
     Ø,5ØØØ,6ØØØ,7ØØØ,8ØØØ,9ØØØ
4ØØØ  GOTO 2ØØØØ
5ØØØ  GOTO 2ØØØØ
8ØØØ  HOME
8Ø1Ø  PRINT "   RECALL FROM DISK"
     : PRINT
8Ø2Ø  PRINT "MAKE SURE DISK IS IN
      PLACE": PRINT
8Ø3Ø  PRINT "NAME OF DATASET IN F
     OLLOWING FORMAT?": PRINT
8Ø4Ø  PRINT "---> NAME-BLOCK#"
8Ø45  PRINT
8Ø47  INPUT "---> ";ND$
8Ø5Ø D$ =  CHR$ (13) +  CHR$ (4)
8Ø55  PRINT
8Ø6Ø  PRINT D$;"OPEN";ND$
8Ø7Ø  PRINT D$;"READ";ND$
8Ø75  INPUT NM$: INPUT TR%
8Ø8Ø  FOR Y = 1 TO TR%
8Ø9Ø  INPUT HN$(Y),TS$(Y),N(Y)
81ØØ  FOR X = 1 TO N(Y)
811Ø  INPUT I%(X,Y)
812Ø  NEXT X
813Ø  NEXT Y
814Ø  PRINT D$;"CLOSE";ND$
8145 ZZ% = 1
815Ø  GOTO 5ØØ
```

```
20000  HOME : REM  HISTOGRAM ROUT
     INE
20005 SC% = 1
20007  HGR : HCOLOR= 7
20010  & SCROLLSET
20020  & OUTLINE
20030  & PLTFMT = 7
20040  GOSUB 40000
20050  VTAB 21
20060  INPUT "TRIAL #? ";Y
20065  FOR H = 0 TO 17:H%(H) = 0:
      NEXT H
20070  FOR X = 1 TO N(Y)
20080  FOR H = 0 TO 15
20090  IF I%(X,Y) > H * 50 - 1 AND
     I%(X,Y) < H * 50 + 50 THEN  GOTO
     20110
20100  GOTO 20200
20110 H%(H) = H%(H) + 2
20115 H = 15
20200  NEXT H
20210  IF I%(X,Y) >  = 800 THEN H
     %(16) = H%(16) + 2
20220  NEXT X
20225  GOSUB 30000
20230  FOR H = 0 TO 17 * 14
20240  & NXTPLT = H%(H / 14) / SC
     %
20250  NEXT H
20260  VTAB 22
20270  PRINT "NEW TRIAL,PRINT, OR
      MENU (N/P/M)
20280  GET A$
20290  IF A$ = "M" THEN  GOTO 500

20300  IF A$ = "N" THEN  GOTO 203
     30
20310  IF A$ = "P" THEN  GOTO 204
     00
20320  GOTO 20280
20330  GOTO 20000
20400  PR# 1
20405  PRINT  CHR$ (9);"G"
20407  PRINT  TAB( 10) LEFT$ (NM$
     ,2); RIGHT$ (ND$,1);" TR #";
     Y;" ";HN$(Y);" ";TS$(Y)
20408  PRINT : PRINT  TAB( 10)"MS
     EC"," ","COUNT": PRINT
20410  FOR H = 0 TO 15
```

```
20420  PRINT  TAB( 10)50 * H;" TO
       ";50 * (H + 1) - 1,H%(H) /
      2
20430  NEXT H
20432  PRINT  TAB( 10)"800 PLUS",
      H%(16) / 2
20435  PRINT
20440  PR# 0
20450  GOTO 20260
30000  REM  HISTOGRAM SCALING ROU
      TINE
30005 MX% = 0
30010  FOR X = 0 TO 15
30020  IF H%(X) > MX% THEN MX% =
      H%(X)
30030  NEXT X
30040  IF MX% / SC% < 127 THEN  GOTO
      30070
30050 SC% = SC% + 1
30060  GOTO 30040
30070  RETURN
40000  FOR X = 0 TO 17 * 14 STEP
      14
40020  FOR Y = 137 TO 140: HPLOT
      X + 14,Y: NEXT Y
40030  NEXT X
40035  & LABEL = ".0" AT 7,145
40040  & LABEL = ".1" AT 35,145
40050  & LABEL = ".2" AT 63,145
40060  & LABEL = ".3" AT 91,145
40070  & LABEL = ".4" AT 119,145
40080  & LABEL = ".5" AT 147,145
40090  & LABEL = ".6" AT 175,145
40100  & LABEL = ".7" AT 203,145
40110  & LABEL = ".8" AT 231,145
40120  & LABEL = "SEC" AT 252,145

40900  RETURN
```

COMPUTER PROGRAM: Experiment 2 — Playback.

```
10  HOME
15  & BOUT,(DV) = 1
20  PRINT "DO YOU WANT A FIXED ON
     -TIME OR SPECIFIC INTERVALS?
      (F/S)"
25  GET A$: IF A$ = "F" OR A$ = "
     S" THEN  GOTO 27
26  GOTO 25
27 Z = 0: IF A$ = "S" THEN Z = 1
50  & BOUT,(DV) = 1
60 X = 0
100  HOME
120  INPUT "STARTING INTERVAL #?
     ";I
124  IF Z = 0 THEN  GOTO 135
125  INPUT "HOW MANY INTERVALS ON
     -TIME? ";N
135 X = 0
140  PRINT : PRINT : PRINT "START
      TAPE"
150  & LOOK FOR BIN,(TV) = B,(TH)
      = 1,(XM) = 65535: & TIMERIN
     ,(TV) = T: & CLRTIMER:X = X +
     1: PRINT X - 2;":";T + 3
155  IF X = I + 1 THEN  GOTO 160
157  GOTO 150
160  & BOUT,(DV) = 0
165  IF Z = 1 THEN  GOTO 200
170  & PAUSE = 1
180  & BOUT,(DV) = 1: GOTO 215
200 X = 0
205  & LOOK FOR BIN,(XM) = 65535,
     (TH) = 1,(TV) = B: & TIMERIN
     ,(TV) = T:X = X + 1: IF X <
     N THEN  GOTO 205
210  & BOUT,(DV) = 1
212  PRINT : PRINT T;"MSEC": PRINT

215  PRINT "HIT 'SPACE' TO CONTIN
     UE": GET A$: GOTO 100
220  GOTO 50
```

Appendix C: Test Words for Input Tasks

Appendix C

List of Test Words for Rhyme Input Task

A. Practice list

Target: a word that rhymes with "rum"

rifle	level	spoon
football	nutmeg	adjective
meter	engineer	orange
text	chimney	whiskey
general	chemistry	minister
nylon	jazz	* drum
cathedral	uncle	francs
desk	copper	gas
crow	legs	hill

B. Experimental lists

1. Target: a word that rhymes with "fear"

bourbon	sister	grasshopper
book	pennies	schooner
coffee	rose	golf
guitar	salt	robin
grape	church	hammer
tin	opal	* ear
classical	hydrogen	colonel
doctor	bat	physics
conjunction	pastor	hotel

2. Target: a word that rhymes with "fair"

diamond	soda	apple
iron	football	priest
beer	schooner	oak
dacron	carrot	centimeter
level	journal	doll
piano	church	oxygen
chisel	aunt	golf
cloves	francs	* bear
canary	doctor	rifle
jazz	mosque	lieutenant
pistol	month	salmon

Appendix C

3. Target: a word that rhymes with "wail"

pea	level	beer
steamer	journal	jazz
bomb	nutmeg	violet
rattle	lieutenant	chisel
baseball	engineer	soda
cathedral	dacron	maple
diamond	drum	priest
sweater	noun	* hail
aunt	crow	chimney
whiskey	apple	perch
iron	ball	electricity

4. Target: a word that rhymes with "feet"

sparrow	finger	bean
adverb	tennis	pearl
sword	peach	elm
lawyer	birch	newspaper
captain	flute	brother
wool	bishop	* sleet
saw	potato	synagogue
shark	tulip	vodka
pear	stove	pepper

Appendix C

List of Test Words for Category Input Task

A. Practice list

Target: a part of a building

legs	spoon	nutmeg
rifle	cathedral	gas
football	adjective	engineer
uncle	desk	hill
meter	orange	drum
copper	crow	* chimney
text	whiskey	chemistry
general	level	francs
nylon	minister	jazz

B. Experimental lists

1. Target: a four-footed animal

orange	pine	pamphlet
block	herring	private
screwdriver	nail	silk
rabbi	pea	temple
spatula	club	verb
dentist	basketball	banana
wine	sapphire	teacher
trumpet	mother	* cow
eagle	gold	cardinal
gun	sugar	game
daisy	violin	carnation

2. Target: a piece of furniture

hotel	bat	doctor
physics	hydrogen	classical
colonel	opal	tin
hammer	church	grape
robin	salt	guitar
golf	rose	* chair
schooner	pennies	coffee
grasshopper	sister	book
pastor	conjunction	bourban

3. Target: a part of the human body

golf	tin	hammer
hydrogen	book	pastor
pennies	colonel	salt
classical	grasshopper	doctor
coffee	hotel	guitar
physics	church	* ear
schooner	conjunction	robin
opal	grape	bat
sister	bourbon	rose

4. Target: an article of clothing

orange	cardinal	gold
trumpet	rabbi	banana
pea	daisy	wine
pamphlet	sapphire	nails
block	temple	sugar
eagle	spatula	teacher
club	pine	violin
private	mother	* tie
screwdriver	verb	game
gun	dentist	carnation
basketball	herring	silk

Appendix D: Analysis of Variance Tables

Appendix D

Table 1

Analysis of Variance Table for Baseline

Tapping Rates (Experiment 1)

Source	Sum of Squares	df	Mean Square	F	p
Hand	12696.0	1	12696.0	26.728	<.001

Appendix D

Table 2

Analysis of Variance Table for Change Indices:

All Language Tasks (Experiment 1)

Source	Sum of Squares	df	Mean Square	F	p
Language Task	.206	5	.041	1.431	.228
Hand	.019	1	.019	2.090	.177
Language Task X Hand	.048	5	.010	2.837	.024

Appendix D

Table 3

Analysis of Variance Table for Change Indices:

Output Language Tasks (Experiment 1)

Source	Sum of Squares	df	Mean Square	F	p
Language Task	.181	3	.060	1.902	.149
Hand	.034	1	.034	6.066	.032
Language Task X Hand	.027	3	.009	2.665	.064

Appendix D

Table 4

Analysis of Variance Table for Change Indices:

Rhyme and Category Language Tasks

(Experiment 1)

Source	Sum of Squares	df	Mean Square	F	p
Language Task	.009	1	.009	.546	.476
Modality	.056	1	.056	1.975	.188
Hand	.013	1	.013	2.145	.172
Language Task X Modality	.031	1	.031	1.929	.193
Language Task X Hand	.000	1	.000	.305	>.500
Modality X Hand	.021	1	.021	4.803	.051
Language Task X Modality X Hand	.015	1	.015	1.975	.188

Appendix D

Table 5

Analysis of Variance Table for Baseline Reaction Times (Experiment 1)

Source	Sum of Squares	df	Mean Square	F	p
Hand	20.165	1	20.165	.002	>.500

Appendix D

Table 6

Analysis of Variance Table for Experimental

Reaction Times (Experiment 1)

Source	Sum of Squares	df	Mean Square	F	p
Language Task	3072.094	1	3072.094	.023	>.500
Hand	5633.371	1	5633.371	.110	>.500
Language Task X Hand	33.332	1	33.332	Very Small	

Appendix D

Table 7

Analysis of Variance Table for Baseline Tapping

Rates: 10 Seconds (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	63.021	1	63.021	.351	>.500
Hand Task	4275.180	1	4275.180	49.738	<.001
Sex X Hand Task	105.021	1	105.021	1.222	.295
Hand	295.020	1	295.020	9.893	.011
Sex X Hand	7.521	1	7.521	.252	>.500
Hand Task X Hand	180.187	1	180.187	8.438	.016
Sex X Hand Task X Hand	105.021	1	105.021	4.918	.051

Appendix D

Table 8

Analysis of Variance Table for Baseline Tapping

Rates: 20 Seconds (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	426.020	1	426.020	.722	.416
Hand Task	16096.684	1	16096.684	59.983	<.001
Sex X Hand Task	54.020	1	540.020	2.012	.187
Hand	1788.519	1	1788.519	57.593	<.001
Sex X Hand	9.188	1	9.188	.296	>.500
Hand Task X Hand	325.520	1	325.520	12.941	.005
Sex X Hand Task X Hand	117.188	1	117.188	4.659	.057

Appendix D

Table 9

Analysis of Variance Table for Baseline Tapping

Rates: 30 Seconds (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	660.098	1	660.098	.558	.473
Hand Task	33074.910	1	33074.910	57.424	<.001
Sex X Hand Task	1518.756	1	1518.756	2.637	.136
Hand	4033.284	1	4033.284	63.506	<.001
Sex X Hand	44.084	1	44.084	.694	.425
Hand Task X Hand	675.004	1	675.004	12.066	.006
Sex X Hand Task X Hand	154.083	1	154.083	2.754	.128

Appendix D

Table 10

Analysis of Variance Table for Change Indices:

10 Seconds (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	.121	1	.121	2.730	.130
Language Task	.373	2	.187	14.883	<.001
Sex X Language Task	.043	2	.021	1.707	.207
Hand Task	.001	1	.001	.028	>.500
Sex X Hand Task	.001	1	.001	.016	>.500
Hand	.019	1	.019	3.302	.100
Sex X Hand	.025	1	.025	4.243	.067
Language Task X Hand Task	.036	2	.018	1.990	.163
Sex X Language Task X Hand Task	.060	2	.030	3.329	.057
Language Task X Hand	.000	2	.000	.039	>.500
Sex X Language Task X Hand	.001	2	.000	.083	>.500
Hand Task X Hand	.003	1	.003	.298	>.500
Sex X Hand Task X Hand	.001	1	.001	.092	>.500
Language Task X Hand Task X Hand	.003	2	.001	1.039	.373
Sex X Language Task X Hand Task X Hand	.000	2	.000	.061	>.500

Appendix D

Table 11

Analysis of Variance Table for Change Indices:

20 Seconds (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	.092	1	.092	1.839	.205
Language Task	.305	2	.152	12.975	<.001
Sex X Language Task	.045	2	.023	1.922	.173
Hand Task	.001	1	.001	.014	>.500
Sex X Hand Task	.005	1	.005	.119	>.500
Hand	.044	1	.044	11.698	.007
Sex X Hand	.055	1	.055	14.691	.004
Language Task X Hand Task	.046	2	.023	2.190	.138
Sex X Language X Hand Task	.048	2	.024	2.268	.130
Language Task X Hand	.003	2	.001	.368	>.500
Sex X Language Task X Hand	.003	2	.001	.352	>.500
Hand Task X Hand	.002	1	.002	.538	.481
Sex X Hand Task X Hand	.003	1	.003	.739	.411
Language Task X Hand Task X Hand	.006	2	.003	3.829	.040
Sex X Language Task X Hand Task X Hand	.001	2	.001	.808	.460

Appendix D

Table 12

Analysis of Variance Table for Change Indices:

30 Seconds (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	.069	1	.069	1.600	.235
Language Task	.238	2	.119	11.226	.001
Sex X Language Task	.056	2	.028	2.635	.097
Hand Task	.001	1	.001	.022	>.500
Sex X Hand Task	.005	1	.005	.127	>.500
Hand	.044	1	.044	22.390	.001
Sex X Hand	.054	1	.054	27.294	<.001
Language Task X Hand Task	.041	2	.021	2.060	.154
Sex X Language Task X Hand Task	.057	2	.029	2.846	.082
Language Task X Hand	.005	2	.002	.850	.443
Sex X Language Task X Hand	.000	2	.000	.017	>.500
Hand Task X Hand	.000	1	.000	.082	>.500
Sex X Hand Task X Hand	.002	1	.002	.721	.416
Language Task X Hand Task X Hand	.002	2	.001	1.095	.354
Sex X Language Task X Hand Task X Hand	.001	2	.000	.429	>.500

Appendix D

Table 13

Analysis of Variance Table for Baseline

Variability (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	9869.922	1	9869.922	3.268	.101
Hand Task	90888.688	1	90888.688	28.314	<.001
Sex X Hand Task	7397.840	1	7397.840	2.305	.160
Hand	496.010	1	496.010	3.455	.093
Sex X Hand	404.259	1	404.259	2.816	.125
Hand Task X Hand	127.075	1	127.075	2.436	.150
Sex X Hand Task X Hand	108.300	1	108.300	2.076	.181

Appendix D

Table 14

Analysis of Variance Table for Experimental

Variability (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	57220.203	1	57220.203	1.540	.243
Language Task	57596.305	2	28798.152	5.897	.010
Sex X Language Task	8876.871	2	4438.434	.909	.419
Hand Task	436071.063	1	436071.063	13.248	.005
Sex X Hand Task	70485.563	1	70485.563	2.141	.175
Hand	590.086	1	590.086	.590	.461
Sex X Hand	1.265	1	1.265	.001	>.500
Language Task X Hand Task	25228.504	2	12614.250	2.517	.106
Sex X Language Task X Hand Task	11198.027	2	5599.012	1.117	.347
Language Task X Hand	186.289	2	93.145	.109	>.500
Sex X Language Task X Hand	685.095	2	342.548	.402	>.500
Hand Task X Hand	1307.425	1	1307.425	2.194	.170
Sex X Hand Task X Hand	130.534	1	130.534	.219	>.500
Language Task X Hand Task X Hand	1597.408	2	798.704	1.757	.199
Sex X Language Task X Hand Task X Hand	1983.977	2	991.989	2.183	.139

Appendix D

Table 15

Analysis of Variance Table for Baseline

Speech Rates: Nursery Rhyme and Prose Tasks

(Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	2262.031	1	2262.031	.891	.368
Language Task	3876.027	1	3876.027	19.447	.002
Sex X Language Task	108.375	1	108.375	.544	.478

Appendix D

Table 16

Analysis of Variance Table for Speech Rate

Decrements: Nursery Rhyme and Prose Tasks (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	189 .844	1	189 .844	.069	>.500
Language Task	33.844	1	33.844	.037	>.500
Sex X Language Task	2.344	1	2.344	.003	>.500
Hand Task	48375.145	1	48375.145	45.973	<.001
Sex X Hand Task	472.595	1	472.595	.449	>.500
Hand	15.844	1	15.844	.080	>.500
Sex X Hand	311.760	1	311.760	1.575	.239
Language Task X Hand Task	333.760	1	333.760	.380	>.500
Sex X Language Task X Hand Task	.010	1	.010	Very Small	
Language Task X Hand	31.510	1	31.510	.252	>.500
Sex X Language Task X Hand	.010	1	.010	Very Small	
Hand Task X Hand	78.844	1	78.844	.546	.477
Sex X Hand Task X Hand	412.510	1	412.510	2.859	.122
Language Task X Hand Task X Hand	372.094	1	372.094	3.819	.080
Sex X Language Task X Hand Task X Hand	44.010	1	44.010	.452	>.500

Appendix D

Table 17

Analysis of Variance Table for Speech Rate

Decrements: Fluency Task (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Sex	2.083	1	2.083	.178	>.500
Hand Task	14.083	1	14.083	9.337	.013
Sex X Hand Task	.333	1	.333	.221	>.500
Hand	2.083	1	2.083	.693	.425
Sex X Hand	8.333	1	8.333	2.770	.128
Hand Task X Hand	5.333	1	5.333	1.969	.191
Sex X Hand Task X Hand	.083	1	.083	.031	>.500

Appendix D

Table 18

Analysis of Variance Table for Speech-Tapping Relation: Nursery Rhyme and Prose Tasks (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Hand Task	11.690	1	11.690	7.321	.114
Language Task	24.908	1	24.908	2.892	.232
Hand	3.643	1	3.643	.535	>.500
State	67.167	1	67.167	267.250	.004
Trial Number	.250	1	.250	.512	>.500
Hand Task X Language Task	.825	1	.825	6.906	.120
Hand Task X Hand	2.130	1	2.130	3.732	.194
Language Task X Hand	.788	1	.788	.083	>.500
Hand Task X State	5.180	1	5.180	1.406	.358
Language Task X State	5.753	1	5.753	2.283	.270
Hand X State	1.843	1	1.843	.667	>.500
Hand Task X Trial	6.355	1	6.355	.392	>.500
Language Task X Trial	3.880	1	3.880	1.113	.402
Hand X Trial	4.378	1	4.378	25.184	.038
State X Trial	3.046	1	3.046	1.746	.318
Hand Task X Language Task X Hand	.363	1	.363	.145	>.500

Appendix D

Table 18 (continued)

Analysis of Variance Table for Speech-Tapping
Relation: Nursery Rhyme and Prose Tasks
(Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Hand Task X Language Task X State	7.763	1	7.763	15.251	.060
Hand Task X Hand X State	3.721	1	3.721	8.062	.105
Language Task X Hand X State	.113	1	.113	.009	>.500
Hand Task X Language Task X Trial	2.700	1	2.700	3.567	.200
Hand Task X Hand X Trial	3.800	1	3.800	.377	>.500
Language Task X Hand X Trial	2.438	1	2.438	6.101	.133
Hand Task X State X Trial	.555	1	.555	.037	>.500
Language Task X State X Trial	4.293	1	4.293	.785	.470
Hand X State X Trial	7.426	1	7.426	48.796	.020
Hand Task X Language Task X Hand X State	.175	1	.175	.120	>.500
Hand Task X Language Task X Hand X Trial	1.378	1	1.378	14.582	.063
Hand Task X Language Task X State X Trial	5.180	1	5.180	32.231	.030

Appendix D

Table 18 (continued)

Analysis of Variance Table for Speech-Tapping Relation: Nursery Rhyme and Prose Tasks (Experiment 2)

Source	Sum of Squares	df	Mean Square	F	p
Hand Task X Hand X State X Trial	1.063	1	1.063	.0766	>.500
Language Task X Hand X State X Trial	.413	1	.413	.381	>.500
Hand Task X Language Task X Hand X State X Trial	2.190	1	2.190	4.418	.171

Appendix E: Individual Data

Appendix E

Table 1

Change Indices and Hand Differences for Nursery Rhyme and Months Task (Experiment 1)

	Nursery Rhyme			Months		
Subject	Right	Left	Difference	Right	Left	Difference
1	3.45	-6.33	9.78	-9.78	.74	-10.02
2	4.48	-2.32	6.80	46.25	38.93	7.32
3	-10.09	-11.07	.17	49.98	47.03	2.95
4	3.43	6.24	-2.81	18.17	20.01	-1.84
5	4.16	-6.39	10.55	-3.49	-13.44	9.95
6	-.13	-15.54	15.41	8.75	-4.34	13.09
7	11.91	-1.29	13.20	-1.91	-3.04	1.13
8	.47	-5.93	6.40	8.51	4.91	3.60
9	-3.22	-5.71	2.49	.40	9.82	-9.42
10	5.90	7.16	-1.26	6.50	9.57	-3.07
11	30.27	26.28	3.99	4.45	23.76	-19.31
12	-1.30	1.10	-2.40	-7.79	-3.77	-4.02
$\bar{X}$	4.04	-1.15	5.19	10.05	10.84	-.79

Appendix E

Table 2

Change Indices and Hand Differences for Rhyme and Category Input Tasks: Individually and Combined (Experiment 1)

	Rhyme			Category			Mean		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
1	7.96	-9.38	17.34	-1.06	11.82	-12.88	3.45	1.22	2.23
2	26.22	10.25	15.97	-7.77	-12.47	4.70	9.23	-1.11	10.34
3	17.09	10.62	6.47	2.30	3.54	-1.24	9.70	7.08	2.62
4	6.97	13.19	-6.22	6.60	16.08	-9.48	6.79	14.64	-7.85
5	11.71	10.03	1.68	8.42	3.28	5.14	10.07	6.66	3.41
6	17.25	-.40	17.65	19.38	16.06	3.32	18.32	7.83	10.49
7	-4.88	-2.10	-2.78	11.39	8.00	3.39	3.26	2.95	.31
8	6.66	16.14	-9.48	7.07	13.67	-6.60	6.87	14.91	-8.04
9	13.81	20.01	-6.20	9.79	25.19	-15.14	11.80	22.60	-10.80
10	-10.45	-16.55	6.10	14.67	9.35	5.32	2.11	-3.60	5.71
11	-18.28	2.68	-20.96	-3.17	5.45	-8.62	-10.73	4.07	-14.79
12	.60	4.21	-3.61	2.70	3.48	-.78	1.65	3.85	-2.20
$\bar{X}$	6.25	4.89	1.36	5.86	8.62	-2.76	6.06	6.76	-.70

Appendix E

Table 3

Change Indices and Hand Differences for Rhyme and Category Output Tasks: Individually and Combined (Experiment 1)

	Rhyme			Category			Mean		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
1	19.89	28.69	-8.80	2.39	-30.42	32.81	11.14	1.87	12.01
2	-5.27	-1.84	-3.43	-2.11	-19.08	16.97	-3.69	-10.46	6.77
3	12.52	10.50	2.02	4.00	3.31	.69	8.26	6.91	1.35
4	19.02	15.29	3.73	21.21	15.03	6.18	20.12	15.16	4.96
5	.48	9.73	-9.25	11.42	-2.46	13.88	5.95	3.64	2.31
6	1.13	-16.52	17.65	-13.00	-29.20	16.20	-5.94	-22.86	16.92
7	13.20	18.78	-5.58	15.14	16.08	-.94	14.17	17.43	-3.26
8	5.63	-10.37	16.00	-11.89	-22.26	10.37	-3.13	-16.32	13.19
9	1.61	-.06	1.67	10.86	1.35	9.51	6.24	.65	5.59
10	-2.27	-4.48	2.21	-7.46	-7.11	-.35	-4.87	-5.80	.93
11	7.78	-2.50	10.28	7.19	10.00	-2.81	7.49	3.75	3.74
12	-7.39	-6.36	-1.03	-2.90	.89	-3.79	-5.15	-2.74	-2.42
$\bar{X}$	5.53	3.41	2.12	2.90	-5.32	8.22	4.22	-.16	5.18

Appendix E

Table 4

Mean Reaction Times in Milliseconds for Baseline and Two Input Tasks (Experiment 1)

	Baseline		Rhyme Input		Category Input	
Subject	Right	Left	Right	Left	Right	Left
1	660	566	1079	925	721	610
2	674	839	1012	1461	945	990
3	651	1009	900	1281	924	1392
4	670	666	1907	1258	701	900
5	581	622	1281	1037	768	812
6	599	511	632	656	768	834
7	540	482	521	700	992	852
8	610	544	545	699	768	834
9	950	677	588	790	1818	699
10	510	514	924	453	700	857
11	815	778	587	678	812	745
12	424	454	746	544	633	745
$\bar{X}$	640	639	894	874	879	856

Appendix E

Table 5

Change Indices and Hand Differences for each Language Task in the Index Tapping Condition: 10 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	6.41	-3.70	10.11	2.56	-11.11	13.67	23.08	0	23.08
4	1.82	2.04	-.22	5.45	8.16	-2.71	3.64	10.20	-6.56
6	6.33	3.17	3.16	3.80	0	3.80	10.13	3.17	6.96
9	0	2.13	-2.13	-5.88	-6.38	.50	-5.88	-2.13	-3.75
11	1.79	-4.26	6.05	1.79	0	1.79	1.79	6.38	-4.59
12	3.17	10.71	-7.54	-3.17	10.71	-13.88	22.22	30.36	-8.14
$\bar{X}$	3.25	1.68	1.57	.76	.23	.53	9.16	8.0	1.16
Females									
2	21.05	6.00	15.05	19.30	16.0	3.30	29.82	32.00	-2.18
3	15.66	-4.65	-10.31	24.53	11.63	12.90	22.64	11.63	11.01
5	4.35	1.61	2.74	2.90	6.45	-3.55	11.59	17.74	-6.15
7	3.33	1.89	1.44	1.67	-1.89	3.56	21.67	0	21.67
8	7.94	1.69	6.25	9.52	5.08	4.12	7.94	3.39	4.55
10	4.76	3.45	1.31	3.17	0	3.17	12.70	6.90	5.80
$\bar{X}$	9.85	1.67	6.16	10.18	6.21	3.97	17.73	11.94	5.75
Total $\bar{X}$	5.55	1.67	3.88	5.47	3.22	2.55	13.45	9.97	3.48

Appendix E

Table 6

Change Indices and Hand Differences for each Language Task in the Sequential Tapping Condition: 10 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	-5.00	9.30	-14.30	0	6.98	-6.98	15.00	23.26	-8.26
4	-4.00	-7.29	3.69	-12.00	-11.54	-.46	0	15.38	-15.38
6	-6.98	-5.26	-1.72	6.98	7.89	-.91	6.98	2.63	4.35
9	0	3.70	-3.70	30.77	14.81	15.96	30.77	33.33	-2.56
11	-12.50	-19.35	6.85	-5.00	-16.13	11.13	17.50	6.45	11.05
12	-16.67	-2.78	-13.89	-22.22	-5.56	-16.66	33.33	30.56	2.77
$\overline{X}$	-7.53	-3.68	-3.85	-.25	-.59	.34	17.26	18.6	-1.34
Females									
2	12.00	9.30	2.70	18.00	11.63	6.37	14.00	34.88	-20.88
3	22.22	20.51	1.71	26.67	20.51	6.16	37.78	23.08	14.70
5	11.11	-9.68	20.79	2.78	-3.23	6.01	11.11	-3.23	14.34
7	2.94	12.50	-9.56	8.82	3.13	5.69	14.71	0	14.71
8	22.81	23.08	-.27	12.28	11.54	.74	14.04	11.54	2.50
10	-23.80	-31.58	7.78	9.52	5.26	4.26	7.14	2.63	4.51
$\overline{X}$	7.88	4.02	3.86	13.01	8.14	4.87	16.46	11.48	4.98
Total $\overline{X}$	.18	.17	.01	6.38	3.77	2.61	16.86	15.00	1.86

Appendix E

Table 7

Change Indices and Hand Differences for each Language Task in the Index Tapping Condition: 20 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	2.14	0	2.14	-2.14	-7.62	5.48	17.86	0	17.86
4	-1.98	0	-1.98	2.97	5.43	-2.46	.99	4.35	-3.36
6	4.00	2.48	1.52	2.67	4.13	-1.46	10.67	3.31	14.04
9	-3.12	-2.25	-.87	-6.25	-7.87	1.62	-5.21	-3.37	-1.84
11	.92	-5.68	6.60	.92	-1.14	2.06	.92	1.14	-.22
12	4.92	5.71	-.79	-.82	7.62	-8.44	25.41	23.81	1.60
$\overline{X}$	1.15	.04	1.11	-.44	.09	-.53	8.44	4.87	3.57
Females									
2	22.52	8.25	14.27	18.02	14.43	3.59	27.93	28.87	4.09
3	5.00	-2.44	7.44	23.00	13.41	9.59	21.00	9.76	11.24
5	4.51	-1.75	6.26	3.01	4.39	-1.38	9.02	9.65	-.63
7	5.31	0	5.31	2.65	-2.04	4.69	22.12	-3.06	25.18
8	9.24	-1.89	11.13	10.92	1.89	9.03	9.24	-1.89	11.13
10	7.26	4.46	2.80	4.84	.89	3.95	14.52	6.25	8.27
$\overline{X}$	8.97	1.11	7.86	10.41	5.50	4.91	17.31	8.26	9.05
Total $\overline{X}$	5.06	.57	4.49	4.98	2.79	2.19	12.87	6.57	6.30

Appendix E

Table 8

Change Indices for each Language Task in the Sequential Tapping Condition: 20 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	-5.00	10.34	-15.34	3.75	5.75	-2.00	11.25	25.29	-14.04
4	-19.57	-16.33	-3.24	-10.87	-12.24	1.37	0	10.20	-10.20
6	-6.10	-1.39	-4.71	6.10	5.56	.54	3.66	0	3.66
9	0	3.77	-3.77	35.69	24.53	11.16	34.62	37.74	-3.12
11	-15.79	-18.64	2.85	-3.95	-13.56	9.61	11.84	10.17	1.67
12	-9.72	0	-9.72	-16.67	-4.29	-12.38	31.94	24.29	7.65
$\bar{X}$	-9.36	-3.71	-5.65	2.34	.96	1.38	15.55	17.95	-2.40
Females									
2	11.34	5.95	5.39	16.49	14.29	2.20	5.15	23.81	-18.66
3	24.44	12.50	11.94	25.56	16.67	8.89	44.44	22.22	22.22
5	7.35	-5.00	12.35	5.88	-5.00	10.88	7.35	-8.33	15.68
7	4.69	0	4.69	7.81	0	7.81	17.19	-7.02	24.21
8	21.70	19.59	2.11	9.43	6.19	3.24	9.43	7.22	2.21
10	-28.92	-34.72	5.80	13.25	2.78	10.47	6.02	1.39	4.63
$\bar{X}$	6.77	-.28	7.05	13.07	5.82	7.25	14.93	6.55	8.38
Total $\bar{X}$	-1.30	-1.99	.69	7.71	3.39	4.32	15.24	12.25	2.99

Appendix E

Table 9

Change Indices and Hand Differences for each Language Task in the Index Tapping Condition: 30 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	.50	0	5.00	-3.96	-8.44	4.48	13.86	0	13.86
4	-4.08	-.73	-3.35	1.36	4.38	-3.02	-1.36	5.11	-6.47
6	3.62	3.91	-.29	1.81	6.15	-4.34	9.95	-2.79	7.16
9	-2.13	-2.24	.11	-6.38	-5.97	-.41	-4.96	-2.99	-1.97
11	-.62	-5.34	4.72	-1.86	-3.05	1.19	.62	-.76	1.38
12	4.89	5.13	-.24	.54	5.77	-5.23	25.00	20.51	4.49
$\overline{X}$	.36	.15	.21	-1.42	-.19	-1.23	7.19	4.11	3.08
Females									
2	18.52	2.27	16.25	16.05	7.58	8.47	25.93	23.48	2.45
3	2.03	-2.46	4.49	22.30	10.66	11.64	18.24	7.38	10.86
5	4.12	-.61	4.73	3.09	3.66	-.57	6.70	6.71	-.01
7	6.63	.69	5.94	2.41	-2.08	4.49	17.47	-4.17	21.64
8	4.73	-1.32	6.05	7.10	.66	6.44	8.28	.66	7.62
10	7.07	3.66	3.41	4.89	0	4.89	15.76	6.10	9.66
$\overline{X}$	7.18	.37	6.81	9.31	3.41	5.90	15.40	6.69	8.71
Total $\overline{X}$	3.81	.25	3.55	3.95	1.61	2.34	11.29	5.40	5.89

Appendix E

Table 10

Change Indices and Hand Difference for each Language Task in the Sequential Tapping Condition: 30 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	-4.20	8.53	-12.73	2.52	9.30	-6.78	9.24	23.26	-14.02
4	-22.86	-16.67	-6.19	-4.29	-15.28	10.99	4.29	9.72	-5.43
6	-7.50	0	-7.50	4.17	6.60	-2.43	.83	2.83	-2.00
9	-1.28	1.28	-2.56	28.21	23.08	5.13	33.33	37.18	-3.85
11	-16.36	-24.14	7.78	-7.27	-12.64	5.37	10.00	5.75	4.25
12	-8.18	0	-8.18	-14.55	-3.88	-10.67	31.82	16.50	15.32
$\overline{X}$	-10.06	-5.17	-4.89	1.47	1.20	.27	14.92	15.87	-.95
Females									
2	10.49	4.00	6.49	17.48	14.40	3.08	4.20	14.40	-10.20
3	22.73	12.15	10.58	25.76	14.95	10.81	39.39	20.56	18.83
5	6.93	-1.10	8.03	5.94	-2.20	8.14	4.95	-6.59	11.54
7	5.21	-1.16	6.37	9.38	-1.16	10.54	13.54	-5.81	19.35
8	20.38	14.60	5.78	9.55	2.19	7.36	4.46	-3.65	8.11
10	-30.08	-31.48	1.40	10.57	3.70	6.87	8.13	-.93	9.06
$\overline{X}$	5.94	-.50	6.44	13.11	5.31	7.80	12.45	3.00	9.45
Total $\overline{X}$	-2.06	-2.80	.74	7.29	3.25	4.04	13.68	9.44	4.24

Appendix E

Table 11

Change Indices and Hand Differences for each Language Task (Index and Sequential Tapping Combined): 10 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	.71	2.80	-2.09	1.28	2.07	-.79	19.04	11.63	7.41
4	-1.09	-2.83	1.74	-3.73	-1.69	-2.04	5.08	16.56	-10.76
6	-.33	-1.05	.68	5.44	3.95	1.49	8.56	2.90	5.66
9	0	2.92	-2.92	12.45	4.22	8.23	12.45	15.60	-3.15
11	-5.36	-11.81	6.45	-1.61	-8.07	6.46	9.65	6.42	3.23
12	-6.75	3.97	-10.72	-12.70	2.58	-15.28	27.78	30.96	-3.18
$\bar{X}$	-2.14	-1.00	-1.14	.26	-.18	.44	13.21	13.3	-.09
Females									
2	16.53	7.65	8.88	18.65	13.82	4.83	21.91	33.04	-11.13
3	13.94	7.93	6.01	25.60	16.07	9.53	30.21	17.36	12.85
5	7.73	-4.04	11.77	2.84	1.61	1.23	11.35	7.26	4.09
7	2.32	7.20	-4.88	5.25	.62	4.63	18.19	0	18.19
8	15.38	12.39	2.99	10.90	8.31	2.59	10.99	7.47	3.52
10	-9.50	-14.07	4.57	6.35	2.63	3.72	9.92	4.77	5.15
$\bar{X}$	7.87	2.85	5.02	11.60	7.18	4.42	17.10	11.71	5.39
Total $\bar{X}$	2.87	.92	1.95	5.93	3.50	2.43	15.16	12.51	2.65

Appendix E

Table 12

Change Indices and Hand Differences for each Language Task (Index and Sequential Tapping Combined): 20 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	-1.43	5.17	-6.60	.81	-.94	1.75	14.56	12.65	1.91
4	-10.78	-8.17	-2.61	-3.95	-3.41	-.54	.50	7.28	-6.78
6	-1.05	.55	-1.60	4.39	4.85	-.46	7.17	1.66	5.51
9	-1.56	.76	-2.32	14.72	8.33	6.39	14.71	17.19	-2.48
11	-7.45	-12.16	4.71	-1.52	-7.35	5.83	6.38	5.66	.72
12	-2.40	2.86	-5.26	-8.75	1.67	-10.42	28.68	24.05	4.63
$\overline{X}$	-4.11	-1.84	-2.27	.95	.53	.42	12.00	11.41	.59
Females									
2	16.93	7.10	9.83	17.26	14.36	2.90	16.54	26.34	-9.80
3	14.72	5.03	9.69	24.28	15.04	9.24	32.72	15.99	16.30
5	5.93	3.38	2.55	4.45	-.31	4.76	8.19	.66	7.53
7	5.00	0	5.00	5.23	-1.02	6.25	19.66	-5.04	24.70
8	15.47	8.85	6.62	10.18	4.04	6.14	9.34	2.67	6.67
10	-10.83	-15.13	4.30	9.05	1.84	7.21	10.27	3.82	6.45
$\overline{X}$	7.87	.42	7.45	11.74	5.66	6.08	16.12	7.41	8.71
Total $\overline{X}$	1.88	-.71	2.59	6.35	3.10	3.25	14.06	9.41	4.65

Appendix E

Table 13

Change Indices and Hand Differences for each Language Task (Index and Sequential Tapping Combined): 30 Seconds (Experiment 2)

	Nursery Rhyme			Prose			Fluency		
Subject	Right	Left	Difference	Right	Left	Difference	Right	Left	Difference
Males									
1	-2.00	4.57	-6.27	-.72	.43	-1.15	11.55	11.69	-.14
4	-13.47	-8.70	-4.77	-1.47	-5.45	3.98	1.47	4.70	-3.23
6	-1.94	1.96	-3.90	2.99	6.38	-3.39	5.39	2.81	2.58
9	-1.71	-.48	-1.23	10.92	8.56	2.36	14.19	17.10	-2.91
11	-8.49	-14.74	6.25	-4.57	-7.85	3.28	5.31	2.50	2.81
12	-1.65	2.57	-4.22	-7.00	.95	-7.95	28.41	18.51	9.90
$\overline{X}$	-4.85	-2.51	-2.34	.03	.51	-.48	11.06	9.99	1.07
Females									
2	14.51	3.14	11.37	16.77	10.99	5.78	15.07	18.94	-3.87
3	12.38	4.85	7.53	24.03	12.81	11.22	28.82	13.97	14.85
5	5.53	-.86	6.39	4.52	.73	3.79	5.83	.06	5.77
7	5.92	-.24	6.16	5.90	-1.62	7.52	15.51	-4.99	20.50
8	12.56	6.64	5.92	8.33	1.43	6.90	6.37	1.48	4.89
10	-11.51	-13.91	2.40	7.73	1.85	5.80	11.95	2.59	9.36
$\overline{X}$	6.56	-.07	6.63	11.21	4.36	6.85	13.93	4.85	9.08
Total $\overline{X}$	.86	-1.29	2.15	5.62	2.44	3.18	12.50	7.42	5.06

Appendix E

Table 14

Change Indices and Hand Differences for all Index Tapping Tasks Combined and all Sequential Tapping Tasks Combined: 10 Seconds (Experiment 2)

	Index			Sequential		
Subject	Right	Left	Difference	Right	Left	Difference
Male						
1	10.68	-4.94	15.62	3.33	13.18	-9.85
4	3.64	6.80	-3.16	-5.33	-1.28	4.05
6	6.75	2.11	4.64	2.33	1.75	.58
9	-3.92	-2.13	-1.79	20.51	17.28	3.23
11	1.79	.71	1.08	0	-9.68	9.68
12	7.41	17.26	-9.86	-1.85	7.41	-9.26
$\bar{X}$	4.39	3.30	1.09	3.16	4.78	-1.62
Females						
2	23.39	18.00	5.39	14.66	18.60	-3 .94
3	17.61	6.20	11.41	28.89	21.37	7.52
5	6.28	8.60	-2.32	8.33	-5.38	13.71
7	8.89	0	8.89	8.82	5.21	3.61
8	8.47	3.39	5.08	16.37	15.39	.98
10	6.88	3.45	3.43	-2.38	-7.90	5.52
$\bar{X}$	11.92	6.61	5.38	12.48	7.88	4.60
Total $\bar{X}$	8.16	5.00	3.16	7.82	5.49	2.33

Appendix E

Table 15

Change Indices and Hand Differences for all Index Tapping Tasks Combined and all Sequential Tapping Tasks Combined: 20 Seconds (Experiment 2)

	Index			Sequential		
Subject	Right	Left	Difference	Right	Left	Difference
Males						
1	5.95	-2.54	8.49	3.33	13.79	-10.46
4	.66	3.26	-2.60	-10.15	-6.12	-4.03
6	5.78	3.31	2.47	1.22	1.39	-.17
9	-4.86	-4.50	-.36	35.16	22.01	13.15
11	.92	-1.89	2.81	-2.63	-7.34	4.71
12	9.84	12.38	-2.54	1.85	6.66	-4.81
$\bar{X}$	3.05	1.67	1.38	2.84	5.07	-2.23
Females						
2	22.82	17.18	5.64	10.99	14.68	-3 .69
3	16.33	6.91	9.42	31.48	17.13	14.35
5	5.51	4.10	1.41	6.86	-6.11	12.97
7	10.03	-1.70	11.73	9.90	-2.34	12.24
8	9.80	-.63	10.43	13.52	11.00	2.52
10	8.87	3.87	5.00	-3.22	-10.18	6.96
$\bar{X}$	12.23	5.00	7.23	11.59	4.03	7.56
Total $\bar{X}$	7.64	3.34	4.30	7.22	4.55	2.67

Appendix E

Table 16

Change Indices and Hand Differences for all Index Tapping Tasks Combined and All Sequential Tapping Tasks Combined: 30 Seconds (Experiment 2)

	Index			Sequential		
Subject	Right	Left	Difference	Right	Left	Difference
Males						
1	3.47	-2.81	6.28	2.52	13.69	-11.17
4	-1.36	2.92	-4.28	-7.62	-7.41	-.21
6	5.13	4.28	.85	-.83	3.14	-3.97
9	-4.26	-3.73	-.53	20.09	20.51	-.40
11	-.62	-3.05	2.43	-4.54	-10.34	5.80
12	10.14	10.47	-.33	3.03	4.21	-1.18
$\bar{X}$	2.04	1.36	.68	2.11	3.97	-1.83
Females						
1	20.17	11.11	9.06	10.72	10.93	-.21
3	14.19	5.19	9.00	29.29	15.88	13.41
5	4.64	3.25	1.39	5.94	-3.30	9.24
7	8.84	-1.85	10.69	9.38	-2.71	12.09
8	6.70	0	6.70	11.46	4.38	7.08
10	9.24	3.25	5.99	-3.79	-9.57	5.78
$\bar{X}$	10.63	3.49	7.14	10.50	2.60	7.90
Total $\bar{X}$	6.34	2.43	3.91	6.31	3.29	3 .02

Appendix E

Table 17

Mean Syllable Output during Nursery Rhyme and Prose Tasks

(Experiment 2)

	Baseline		Index				Sequential			
Subject	Rhyme	Prose	Rhyme		Prose		Rhyme		Prose	
			Right	Left	Right	Left	Right	Left	Right	Left
1	256	255	287	285	268	299	215	226	242	267
2	191	156	236	215	153	146	137	130	134	124
3	150	113	157	169	126	117	138	145	126	141
4	227	199	294	284	225	213	193	205	141	192
5	182	150	204	215	178	177	145	152	110	120
6	233	212	285	278	240	229	248	221	165	162
7	227	206	225	231	235	233	172	156	173	159
8	218	225	270	272	270	260	231	193	225	236
9	179	165	162	162	177	156	157	173	131	149
10	265	205	296	282	243	251	276	260	162	132
11	205	153	180	212	155	142	145	145	125	119
12	224	213	258	252	282	264	239	241	255	251
$\bar{X}$	213	188	238	238	213	207	191	187	166	171
Nursery Rhyme and Prose Combined										
$\bar{X}$	200		224				179			

Appendix E

Table 18

Mean Word Output during Fluency Task (Experiment 2)

Subject	Baseline	Index Right	Index Left	Sequential Right	Sequential Left
1	17	19	18	18	17
2	15	16	16	15	15
3	13	12	10	6	11
4	8	8	8	8	9
5	11	13	9	9	11
6	12	12	11	11	13
7	14	16	15	14	16
8	19	19	22	20	21
9	12	12	9	10	8
10	24	20	27	19	22
11	16	14	14	13	12
12	17	18	17	14	16
$\bar{X}$	14.83	14.92	14.67	13.08	14.25
Right and Left Combined $\bar{X}$		14.8		13.7	

Appendix E

Table 19

Mean Number of Syllables per Second, Overall and During Intervals, for each Task: Nursery Rhyme and Prose (Experiment 2)

Nursery Rhyme/Index

Subject	Trial	Right Overall	Right Interval	Left Overall	Left Interval
1	a	9.1	7.3	8.9	8.7
	b	9.4	3.6	9.4	10.6
2	a	7.9	3.0	6.1	2.0
	b	7.3	10.1	7.8	1.9
3	a	5.1	0	5.0	3.7
	b	5.1	3.5	5.9	6.0

Normal Prose/Index

Subject	Trial	Right Overall	Right Interval	Left Overall	Left Interval
1	a	7.8	10.7	9.1	9.5
	b	9.5	3.0	10.2	5.0
2	a	4.8	0	4.6	4.8
	b	5.1	0	4.8	2.0
3	a	4.0	0	3.2	2.7
	b	4.1	4.3	4.4	4.8

Table 19 (continued)

Nursery Rhyme/Sequential

Subject	Trial	Right Overall	Right Interval	Left Overall	Left Interval
1	a	6.9	3.5	7.2	8.1
	b	7.0	9.2	7.4	7.7
2	a	4.5	7.8	4.1	4.0
	b	4.3	5.7	4.3	4.0
3	a	4.5	5.1	4.8	5.9
	b	4.4	0	4.6	1.2

Normal Prose/Sequential

Subject	Trial	Right Overall	Right Interval	Left Overall	Left Interval
1	a	7.7	4.2	8.5	8.0
	b	7.9	9.4	8.7	1.5
2	a	4.3	1.8	4.1	2.4
	b	4.4	1.6	3.9	1.2
3	a	4.3	1.7	5.1	5.1
	b	3.8	1.0	3.9	1.6

Appendix E

Table 20

Speech Output During Long Intervals: Nursery Rhyme and Prose Tasks

(Experiment 2)

Subject	Hand	Mean Interval(ms)	Interval(s) Examined(ms)	Speech Output
Nursery Rhyme/Index				
1	Right	152.6	413	(litt)le lamb; its...
	Left	188.2	343	-sure to go.
	Right	146.5	280	-go.(breath)
	Left	204.3	377	the lamb was sure...
2	Right	226.8	337	was wh(ite)...
	Left	228.2	506	(s)now;
	Right	232.5	369	(s)now; And every-...
	Left	241.4	522	(breath) M(ary)...
3	Right	209.9	284	- - - -
	Left	235.4	541	Mary...
	Right	206.7	284	go.
	Left	247.9	496	was white as...
Normal Prose/Index				
1	Right	146.7	280	Driving was...
	Left	179.1	315	I left ear(ly).
	Right	140.3	332	(sl)ow...
	Left	183.1	397	(pause)woke up...
2	Right	231.1	545	- - - -
	Left	261.0	620	was snowing;
	Right	210.4	699	- - - -

Table 20 (continued)

	Hand	Mean Interval(ms)	Interval(s) Examined(ms)	Speech Output
	Left	234.8	497	(sno)wing;
3	Right	271.5	581	- - - -
	Left	278.1	728	When L..
	Right	249.5	469	(Dr)iving...
	Left	275.6	412	this morn(ing)...

Nursery Rhyme/Sequential

Subject	Hand	Mean Interval	Interval(s) Examined	Speech Output
1	Right	245.2	427 and 438	white as snow;
	Left	255.3	742	everywhere that Mary w(ent), (note-subject omitted "and")
	Right	242.1	653	lamb; its fleece was white as...
	Left	256.7	652	fleece was white as snow;
2	Right	234.0	514	And everywhere...
	Left	254.1	499	Its fleece...
	Right	239.5	524	had a litt(le)...
	Left	249	498	white as...
3	Right	315.0	587	was white as...
	Left	309.0	508	that Mary...
	Right	280.4	1014	uh-s-...
	Left	330.5	1613	(w)ent, its-uh-uh...

Table 20 (continued)

Normal Prose/Sequential

	Hand	Mean Interval(ms)	Interval(s) Examined(ms)	Speech Output
1	Right	240.8	442 and 514	it was snowing;
	Left	244.8	628	this morning, it was...
	Right	285.1	531 and 634	Driving was slow, but I got to work on time.
	Left	271.2	672	time.
2	Right	265.0	519 and 619	snowing;
	Left	287.6	818	(sn)owing;
	Right	248.1	639	so...
	Left	278.2	823	(t)ime.
3	Right	293.6	596	Dri(ving)...
	Left	325.9	785	it was snowing;
	Right	322.8	977	I (pause) g(ot)...
	Left	334.2	1220	on time.

Appendix E

Table 21

Speech Output During Long Intervals: Fluency Task (Experiment 2)

Subject	Hand	Mean Interval	Interval Examined	Speech Output
Index Tapping				
1	Right	174.5	400	Cat
	Left	197.7	376	(heigh)t
	Right	171.8	531	- - -
	Left	192.8	294.6	(bui)lt
2	Right	260.3	887	-ry, um
	Left	317.5	893	um....
	Right	241.9	504	boi(strous)
	Left	284.8	1505	d-done-done...
3	Right	239.3	445	- - -
	Left	257.3	484	- - -
	Right	261.6	320	- - -
	Left	279.4	629	aw...
Sequential Tapping				
1	Right	269.4	678	post(er)
	Left	301.6	713	- - -
	Right	292.8	789	mat
	Left	311.3	643 and 563	t-um
2	Right	249.3	590 and 1299	frank, foot
	Left	364.2	1514	p-uh
	Right	196.2	333	man
	Left	228.5	1044	- - -

Table 21(continued)

Subject	Hand	Mean Interval	Interval Examined	Speech Output
3	Right	399.7	1093 and 1113	um-s,s
	Left	378.1	651 and 863	uh,girl
	Right	352.8	709	(rif)le
	Left	337.03	615	um

BIBLIOGRAPHY

Annette, M. A classification of hand preference by association analysis. British Journal of Psychology, 1970, 61, 303-321.

Battig, W. F., and Montague, W. E. Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. Journal of Experimental Psychology Monograph, 1969, 80, 1-46.

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

Campbell, R., and Dodd, B. Hearing by eye. Quarterly Journal of Experimental Psychology, 1980, 32, 85-99.

Crowder, R. G. The purity of auditory memory. Phil. Trans. R. Soc. Lond., 1983, B302, 251-265.

Curtiss, S. Genie: A psycholinguistic study of a modern day "Wild Child". New York: Academic Press, 1977.

Day, J. Right hemispere language processing in normal right-handers. Journal of Experimental Psychology: Human Perception and Performance, 1977, 3, 518-528.

Dennis, M., and Kohn, B. Comprehension of syntax in infantile hemiplegics after cerebral hemidecortication: Left hemisphere superiority. Brain and Language, 1975, 2, 472-482.

Dennis, M., and Whitaker, H. A. Language acquisition following hemidecortication: Linguistic superiority of the left over the right hemisphere. Brain and Language, 1976, 3, 404-433.

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

Hellige, J., and Longstreth, L. E. Effects of concurrent hemisphere-specific activity on unimanual tapping rate. Neuropsychologia, 1981, 19, 395-405.

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

Hicks, R. E., Bradshaw, G. J., Kinsbourne, M., and Feigin, D. Vocal-manual trade-offs in hemispheric sharing of human performance control. Journal of Motor Behavior, 1978, 10, 1-6.

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

Hiscock, M. Verbal-manual time sharing in children as a function of task priority. Brain and Cognition, 1982, 1, 119-131.

Hiscock, M., and Kinsbourne, M. Ontogeny of cerebral dominance: Evidence from time-sharing asymmetry in children. Developmental Psychology, 1978, 14, 321-329.

Hiscock, M., and Kinsbourne, M. Asymmetry of verbal-manual time sharing in children: A follow-up study. Neuropsychologia, 1980, 18, 151-162.

Hiscock, M., Kinsbourne, M., Samuels, M., and Krause, A. E. The development of dual-task performance: Generalized and lateralized effects of speaking and memory encoding upon the rate and variability of children's finger tapping. Manuscript submitted for publication, 1983.

Hughs, M., and Sussman, H. M. An assessment of cerebral dominance in language disordered children via a time sharing paradigm. Manuscript submitted for publication, 1982.

Ibbotson, N. R., and Morton, J. Rhythm and dominance. Cognition, 1981, 9, 125-138.

Johnson, O., and Kozma, A. Effects of concurrent vebal and musical tasks on a unimanual skill. Cortex, 1977, 14, 11-16.

Kahneman, D. Attention and effort. New Jersey: Prentice-Hall, Inc., 1973.

Kahneman, D. Effort, recognition, and recall in auditory attention. In P. M. Rabbit and S. Dornic (Eds.), Attention and Performance V. New York: Academic Press, 1975.

Kelso, J. A. S., Holt, D. G., Rubin, P. N., and Kugler, P. Patterns of human interlimb coordination emerge from properties of non-linear, limit cycle ossilatory processes: Theory and data. Journal of Motor Behavior, 1981, 13, 226-261.

Kelso, J. A. S., Tuller, B., Harris, K. A 'dynamic pattern' perspective on the control and coordination of movement. In P. MacNeilage (Ed.), The production of speech. New York: Springer-Verlag, 1983.

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

Kimura, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 1964, 15, 166-171.

Kimura, D. The neural basis of language qua gesture. In H. Avakian-Whitaker and H. A. Whitaker (Eds.), Studies in neurolinguistics (Vol. 2). New York: Academic Press, 1976.

Kimura, D., Battison, R., and Lubert, B. Impairment of non-linguistic hand movements in a deaf aphasic. Brain and Language, 1976, 4, 566-571.

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

Kinsbourne, M., and Hicks, R. H. Functional cerebral space: A model for overflow, transfer, and interference effects in human performance. In J. Requin (Ed.), Attention and performance VII. New York: Academic Press, 1978.

Kinsbourne, M., and Hiscock, M. Asymmetries of dual-task performance. In J. Hellige (Ed.), Cerebral functional asymmetry: Theory, measurement, and application. New York: Praeger, 1983.

Klima, E. S., and Bellugi, U. The signs of language. Cambridge: Harvard University Press, 1979.

Klingman, K. C., and Sussman, H. M. Hemisphericity in aphasic language recovery. JSHR, 1983, 26, 249-256.

Levy, J. Psychobiological implications of bilaterial asymmetry. In S. Dimond and J. Beaumont (Eds.), Hemispheric function in the human brain. New York: John Wiley and Sons, 1974.

Lomas, J. Competition within the left hemisphere between speaking and unimanual tasks performed without visual guidance. Neuropsychologia, 1980, 18, 141-149.

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

McFarland, K., and Ashton, R. The influence of concurrent task difficulty on manual performance. Neuropsychologia, 1978, 16, 735-741. (a)

McFarland, K., and Ashton, R. The lateralized effects of concurrent cognition and motor performance. Perception and Psychophysics, 1978, 23, 344-349. (b)

McFarland, K., and Geffen, G. Speech lateralization assessed by concurrent task performance. Neuropsychologia, 1982, 20, 383-390.

Milner, B. Laterality effects in audition. In V. B. Mountcastle (Ed.), Interhemispheric relations and cerebral dominance. Baltimore: Johns Hopkins, 1962.

Moray, N. Where is capacity limited? A survey and a model. Acta Psychologica, 1967, 27, 84-92.

Moscovitch, M. On the representation of language in the right-hemisphere of right-handed people. Brain and Language, 1976, 3, 47-71.

Neville, H. J., and Bellugi, U. Patterns of cerebral specialization in congenitally deaf adults: A preliminary report. In P. Siple (Ed.), Understanding language through sign language research. New York: Academic Press, 1978.

Peters, M. Handedness: Coordination of within- and between-hand alternating movements. American Journal of Psychology, 1981, 94, 633-643.

Robinson, G. M., and Solomon, D. J. Rhythm is processed by the speech hemisphere. Journal of Experimental Psychology. 1974, 102, 508-511.

Spoehr, K. J., and Corin, W. J. The stimulus suffix as a memory coding phenomenon. Memory and Cognition, 1978, 6, 583-589.

Studdert-Kennedy, M. Language by hand and eye: A review of Edward S. Klima and Ursula Bellugi's The signs of language. Cognition, 1980, 8, 93-108.

Summers, J., and Sharp, C. A. Bilateral effects of concurrent verbal and spatial rehearsal on complex motor sequencing. Neuropsychologia, 1979, 17, 331-343.

Sussman, H. M., Franklin, P., and Simon, T. Bilingual speech: Bilateral control? Brain and Language, 1982, 15, 125-142.

Tillman, D. Clustering by aphasics in free recall. Unpublished doctoral dissertation, CUNY, 1975.

Tinsley, V. S., and Waters, H. S. The development of verbal control over motor behavior: A replication and extension of Luria's findings. Child Development, 1982, 53, 746-753.

Wilke, J. T., Lansing, R. W., and Rogers, C. A. Entrainment of respiration to repetitive finger tapping. Physiological Psychology, 1975, 3, 345-349.

Zaidel, E. Concepts of cerebral dominance in the split brain. In P. Buser and A. Rougeul-Buser (Eds.), Cerebral correlates of conscious experience. Amsterdam: Elsevier/North-Holland Biomedical Press, 1978. (a)

Zaidel, E. Lexical organization in the right hemisphere. In P. Buser and A. Rougeul-Buser (Eds.), Cerebral correlates of conscious experience. Amsterdam: Elsevier/North-Holland Biomedical Press, 1978. (b)