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*Brigham Young University - Provo*

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THE EFFECTS OF DIVIDED ATTENTION ON SPEECH MOTOR, VERBAL  
FLUENCY AND MANUAL TASK PERFORMANCE

by

Erin Hamblin

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Audiology and Speech-Language Pathology

Brigham Young University

August 2005

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Erin Hamblin

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

\_\_\_\_\_  
Date

\_\_\_\_\_  
Christopher Dromey, Chair

\_\_\_\_\_  
Date

\_\_\_\_\_  
David McPherson

\_\_\_\_\_  
Date

\_\_\_\_\_  
Ron Hager

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Erin Hamblin in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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Date

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Christopher Dromey  
Chair, Graduate Committee

Accepted for the Department

---

Ron W. Channell  
Graduate Coordinator

Accepted for the College

---

K. Richard Young  
Dean, David O. McKay School of Education

## ABSTRACT

### THE EFFECTS OF DIVIDED ATTENTION ON SPEECH MOTOR, VERBAL FLUENCY AND MOTOR TASK PERFORMANCE

Erin Hamblin

Department of Audiology and Speech-Language Pathology

Master of Science

Research in dual task performance varies widely in its methodology and results. The present study employed three different types of activity to provide insights into the interference that occurs in dual task performance. Twenty young adults completed a speech task (repeating a sentence), a verbal fluency task (listing words beginning with the same letter), and right- and left-handed motor tasks (placing pegs and washers in a peg board) in isolation and in concurrent conditions. Speech kinematic data revealed that during concurrent performance of manual tasks, lip displacement and peak velocity decreased, while sound pressure level and spatiotemporal variability increased. The impact of manual motor performance on speech differed between the right and left hand. Manual motor scores significantly decreased when concurrently performed with the verbal fluency task. Also, verbal fluency results declined when performed concurrently

with left-handed manual motor task. These findings suggest that cortical localization of control may be more complex than is predicted by the functional distance hypothesis.

## ACKNOWLEDGMENTS

At the time of onset, it was difficult to know exactly how many people would be instrumental in helping me to complete this work. However, hindsight often serves as a reminder of the support and understanding of others that I did not fully recognize at the time. I hope those mentioned here understand that how greatly I appreciate their support and encouragement even though I might not have let them know at the time. I would like to thank my parents, brothers, and sister for their love and support of my efforts. I want to thank my fellow students. Their timely sense of humor and kind words helped me to continue trudging on when the way seemed rather bleak. Finally, I wish to thank Dr. Christopher Dromey. Without his knowledge and understanding, I would not have gotten very far. His patience and love for learning made this experience a positive one from which I have gleaned important information that will shape my career. Thank you all for the support that you have given me to help me reach this point in my life.

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## Introduction

Communication is a dynamic process, which takes place in many settings. People today lead busy lives, engaging in communication while involved in other activities. Everyday interactions confirm the observation that “situations that require divided attention [between multiple tasks] are the rule, not the exception” (Lane, 1982). At times, the brain is able to process concurrent demands effectively; however, at other times it is not as successful, and this may result in observable changes in performance.

The way in which the brain handles multiple simultaneous demands has been studied extensively by cognitive psychologists. Experimentation on this topic, which is often referred to as *dual task* or *concurrent task* performance, has given rise to several sets of theories that attempt to explain how the brain copes with the demands placed on it. The experimental methodology requires participants to perform tasks first in isolation and then simultaneously with another task. The researchers then analyze the individual’s performance to try to better understand how the brain works. Interference, or a decline in the rate and/or accuracy of task performance, is attributed to an inability of the brain to meet the simultaneous task requirements. Theories developed to explain this interference fit into one of three main categories that can be referred to as capacity theories, bottleneck theories, and neurological theories (Pashler, 1998).

Supporters of different theories favor specific types of experimental methodologies, which have yielded a variety of insights into dual task performance. Capacity theorists utilize continuous tasks in which the participant is asked to complete certain activities for a specified duration (from 30 seconds to 1 minute). Bottleneck theorists rely more heavily upon reaction time tasks in which the participant is presented

with stimuli requiring a rapid response (i.e. pushing a button in response to a picture, or vocalizing in response to a tone). Neurological theorists attempt to provide a physiological explanation for their experimental findings, and claim that anatomical and physiological characteristics of the brain account for interference seen in dual task performance.

Capacity theorists initially developed the idea of a “central processor,” referred to as *the single processor hypothesis* (Allport, Antonis, & Reynolds, 1972). They described the central processor as a single and finite “pool” of resources that are accessed as needed to perform the required tasks. The brain then allocates the appropriate amount of resources (often equated with attention) to a task, based on its complexity. As long as the demands do not exceed the capacity of the central processor, the brain is able to perform the tasks efficiently. However, once the capacity is exceeded, the accuracy of performance will decline. When the brain is no longer able to effectively meet all the demands, the individual then preferentially attends to one task over the other based on his or her motivation (Kahneman, 1973). This results in differential performance between the tasks. Experiments controlling for the amount of effort expended on each task demonstrated a consistent trade-off between effort invested in the task and the accuracy of the performance. As the performance accuracy of the first task increased, the accuracy of the second task decreased. This concept is referred to as graded capacity sharing.

Allport and colleagues (1972) challenged the single processor theory. These researchers designed a pair of experiments to test tasks which were judged to be similar in difficulty but of different types (i.e. speech, motor, music). The single processor theory predicted that any task of equivalent difficulty, regardless of type, would cause the same

amount of interference, but as the level of difficulty increased so would the interference that resulted. The first experiment required the participants to verbally shadow (i.e., speak out loud an essay passage as it was presented through headphones) while attempting to memorize a list of concrete nouns. The experimenters used pictures, print, and speech to present the list for memorization. The results did not coincide with the predictions of the single processor hypothesis. While participants had near perfect recall of the pictures, recall for the printed and heard words was significantly lower.

The second experiment by Allport and colleagues involved dual task performance of verbal shadowing and sight-reading a piano score. Difficult and easy versions of each task were paired in all possible combinations. Again, the results did not support the single processor hypothesis. Error rates in shadowing and recalling the content of the verbal passage did not correspond to the difficulty of the piano score.

In light of these findings, Allport and his colleagues (1972) hypothesized that instead of a single channel, the brain utilizes multiple smaller processors, each being responsible for the encoding of different types of information. This model, known as *the multi-channel hypothesis*, could account for the relatively unimpaired performance of two complex but fundamentally different tasks as well as the interference that occurred when performing two comparably complex but similar tasks.

Subsequent research on divided attention tasks attempted to define the processing boundaries of these multiple channels; which processors performed which type of processing. However, the definition of the boundaries separating one channel's processing domain from another remains controversial. Simple theories based on input and output mode are unable to account for the diverse research findings. In an attempt to

better explain the data, Wickens (1984) proposed a complex multi-dimensional view of these processing channels by breaking down the cognitive demands of a task according to stage of processing, coding type, input modality, and response modality. These characteristics determined the types of processing needed to complete each task. The brain then utilizes a distinct channel for processing based upon the characteristics of the task being completed. This multi-dimensional view of task processing theoretically accounts for the graded amount of interference observed in experiments. However, applying this model to define the difficulty of experimental tasks becomes cumbersome and unrealistic in experimental settings. Research continues in an attempt to provide a more functional explanation.

*Bottleneck theories* present an alternative view of task performance. These theories are based largely upon the results of reaction time experiments. Investigators present two different types of stimuli in close succession and measure the participant's ability to quickly respond to each cue. Processing the presented stimuli is commonly broken down into multiple steps or stages. These stages include memory retrieval, decision selection, response selection, response initiation, and response execution. The reaction time for the second task is greater than that for the initial task, but much shorter than the combined time to complete each task individually. Manipulation of the experimental variables has isolated the response selection stage as often causing the delay in the response time for the second task. It appears that the stages occurring before and after response selection can take place simultaneously for the different tasks. However, response selection can only be performed for one task at a time, requiring exclusive use of that specific pathway (Pashler & Johnston, 1998).

*The time-sharing model* offers a version of the bottleneck theory adapted to account for the results of the continuous task experiments. The time-sharing view suggests that the brain quickly alternates between tasks, giving full attention to one and then the other in a back and forth switching process. “Chunking,” the selection of several responses at a time, allows portions of a task to be executed without requiring the use of the critical response selection network. While execution is being performed for one task, full attention is given to the other task, carefully avoiding the resource-sharing characteristic of capacity theories (Baddeley, 1998).

In continuous task performance, preferential allocation of attention (as directed by the experimenter) gives fairly consistent results. As resource allocation for one task goes up, the performance of the other task declines. Graphed results show a relatively smooth “trade-off” curve depicting this inverse relationship. Capacity theorists interpret these results to support the sharing of attentional resources in a graded fashion. However, time-sharing could also produce the same results. As participants preferentially target one task over another, they may simply be attending to one task for a greater length of time before switching attention to the other task. The continuous task design and averaging of results over many trials and participants may obscure information concerning the actual method of attending to two tasks simultaneously (Pashler, 1998).

Ho, Iansak, and Bradshaw (2002) in a recent study have proposed that decreases in motor speech skills in individuals with Idiopathic Parkinson’s Disease (IPD) are due to deterioration in attention allocation skills. Individuals with IPD performed motor speech (spontaneous speech or reciting numbers) and visuomotor (manually-controlled tracking of a visual target) tasks concurrently. The findings revealed a marked decline in speech



performance in both tasks, such as delayed speech onset time, rate, and overall intensity. The authors suggested that the patients were unable to effectively allocate attentional resources among competing demands. This resulted in an increased need for attention to perform what were previously well-learned, semi-automatic tasks.

The previously discussed theories provide their explanation of cognitive processing solely in psychological terms. A theory developed by Kinsbourne suggests a neurophysiological explanation for dual task interference. The *functional distance hypothesis* (Kinsbourne & Hicks, 1978) correlates well with cortical mapping research that has identified specific areas of the brain that are more active when performing a given task. Kinsbourne and Hicks claimed that the amount of interference manifest when performing multiple tasks is inversely related to the distance between areas of the brain which are activated for those tasks. Therefore, two tasks utilizing relatively separate areas of the brain will show a decreased amount of interference in performing both tasks. But, when two tasks utilize “highly linked neural network[s]” in close proximity to each other, there is an increased risk of cross talk between the active neurons, observed behaviorally as a decline in performance (p. 346).

Studies show that most individuals, especially those who are right-handed, have receptive language function localized to the perisylvian region of the left temporal lobe, known as Wernicke’s area. The frontal lobe contains the areas associated with motor movement known as the precentral gyrus of each hemisphere, also referred to as the motor strip. Motor movement is contralaterally controlled; the motor strip located in the right hemisphere is responsible for movement in the left side of the body and vice versa. Speech motor control is localized in Broca’s area (also known as the frontal operculum),

which is located above the inferior frontal gyrus of the left hemisphere.

According to the functional distance hypothesis, differences between right and left sided limb performance might be found in concurrent task conditions with speech and language because the left hemisphere motor strip and language areas of the brain are anatomically closer. Research to test this theory has largely focused on individuals who are right hand dominant, because right-handed individuals typically have language localized to the left hemisphere. The hypothesized interference derives from links between hand dominance and language localization within the brain. Right hand dominance means that right-handed performance will be more skilled than when the same task is performed with the left hand. Greater performance decrements of right hand performance in dual task situations involving communication might be observed because the loci of control for the right hand, speech, and language are located within the same hemisphere of the brain.

Several concurrent task studies have found just such an effect when comparing left- or right-sided motor movement with speech and language tasks (Chang & Hammond, 1987; Hiscock, Kinsbourne, Samuels, & Krause, 1985; Seth-Smith, Ashton, McFarland, 1989; Simon & Sussman, 1986). These studies found that the performance for each hand declined in a dual task situation. The right hand, however, manifested a greater decline from its baseline performance than the left hand did. Interpretations of the results vary among the researchers. It is also notable that the same asymmetrical effect has not been found in studies of individuals who are left hand dominant or who have language disorders associated with a lack of language lateralization to the left hemisphere (Lomas & Kimura, 1976).

The study performed by Seth-Smith et al. (1989) found a significant decline in the performance of finger tapping and a variety of language tasks (listening to a story, silently retelling the story, and vocally retelling the story). The purpose of the study was to determine if differences in task performance could be observed and attributed to differences in language lateralization between males and females. The researchers found a significant increase in the deviation from tapping rate when the story was retold aloud. The lack of similar lateralized interference for the silent story retelling indicated that the motor speech component of vocalization may play a role in the observed cognitive interference.

Hiscock et al. (1985) performed a similar study, which examined speaking and finger tapping rate in children. Seventy-three children (grades 1-4) participated in the study, in which their maximum tapping rate was determined in isolation and then concurrently with nursery rhyme repetition. The children demonstrated similar patterns of asymmetrical interference for the right hand. Although the extent to which the concurrent task interfered with tapping decreased with an increase in age, a consistent asymmetry was seen throughout all age groupings. These authors concluded that consistent performance on the communication task indicated that preferential treatment of the speech task over the motor task was unlikely.

Simon and Sussman's (1987) study paired finger tapping and various language tasks (picture descriptions, reading aloud, or producing a monologue) in 260 participants. Participants were divided into groups based on gender, handedness, and family history of left-handedness. The number of taps was recorded in isolation and then during concurrent performance. A greater decrease from baseline performance was found for the dominant

hand regardless of whether the participant was right- or left-handed.

Chang and Hammond (1987) examined variation in participant performance by utilizing speech and finger tapping tasks while varying the amplitude of a desired response. Finger tapping while repeating the word /stak/ for 10 seconds with continuous amplitude in both tasks (finger tapping and speech stress) was considered the baseline condition. The amplitude of finger tapping was then varied with speech stress held constant. Finally, speech stress was modulated while finger tapping was held constant. Although the effect was not statistically significant, most participants showed greater deviation from constant amplitude in tapping with the right hand when paired with speech. However, it has been suggested that finger tapping may lack the complexity needed to stress the motor system, which might contribute to asymmetrical interference (Whitall, 1996).

Different researchers have offered contrasting explanations for this phenomenon. Seth-Smith et al. (1989) asserted that their findings did not support the functional distance hypothesis. Instead, they proposed that the motor aspect of producing speech relied upon the same processing resources as the movement of the right hand, which resulted in interference. Hiscock et al. (1985) claimed that time sharing of attention best explained the results, because the older children were more accurate in their performance, which they attributed to more advanced cognitive maturation.

Simon and Sussman (1987) claimed that their findings of greater decline in the dominant hand for both right- and left-handed participants indicated a breakdown in the motor performance system only. The interference observed in left-handed individuals would not indicate the interference to be the result of challenging a specific region of the

brain. They suggested that interference can be traced to lack of strict contralateral control of motor performance. The left-handed interference might be due to ipsilateral contributions to left-handed finger tapping. The dominant hand (right or left) had simply developed a level of skill that provided greater opportunity for interference from concurrent demands. Chang and Hammond (1987) proposed a “functional bidirectional linkage” between speech and manual movement. They concluded from their experimental data that they could not rule out the presence of asymmetrical interference effects seen in the right hand (p. 272).

Recent developments in the scientific methods of quantifying dual task performance provide the opportunity for reevaluating the phenomena of asymmetrical manual task interference. The demonstration of a bidirectional influence between tasks (Dromey & Bates, in press) and the development of more sensitive measurements of speech performance, such as the Spatiotemporal Index (STI; Smith, Goffman, Zelaznik, Ying, & McGillem, 1995), can provide additional insight into the influence that manual motor and speech tasks have upon one another.

A challenge in the study of concurrent task performance is the potential complication of learning effects. As a task is performed, the initial performance accuracy may be poor, but it improves with practice. This is true for simple and complex task performance, such as reading while writing from dictation (Spelke, Hirst, & Neisser, 1976). Automatization is a term that is commonly used to describe this phenomenon (Leclercq, 2002). The performance of a novel task initially requires a greater depth of processing, evaluating all of the potential demands and possible responses. However, with repeated practice, the participant is able to develop expectations for the task. Greater

familiarity with performing a task results in a decreased need for in-depth processing. More superficial processing then allows for more resources to be available for the performance of another task.

Another source of complication in developing a widely applicable theory for dual task performance is the diverse array of tasks and measurements employed in the research literature. The diversity in task modality, level of difficulty, and the measurement of performance result in conflicting research findings. While some researchers have found that even simple tasks (such as finger tapping, speech shadowing, and drawing) are subject to interference (Klapp, Porter-Graham, & Hoifjeld, 1991), others have not (LaBarba, Bowers, Kingsberg, & Freeman, 1987).

As mentioned earlier, reaction time and continuous tasks are both utilized in concurrent task performance studies; however, these tasks are fundamentally different in nature. Reaction time tasks are much simpler and are often not applicable to daily life. While continuous tasks can come closer to approaching our daily actions, they can vary greatly in difficulty and applicability. Some tasks are simplified for the sake of measurability, but lose all relevance to typical human movement (i.e. repeated rapid finger tapping). Other tasks designed to simulate real life conditions (i.e. spontaneous monologue production) become difficult to measure, and thus lose efficacy in controlled experiments.

Motor tasks are often limited to tapping fingers or feet, pointing, or pressing a key in response to stimuli. While these tasks are easily quantifiable, the movements fail to reflect the complicated nature of the motor gestures that are a large part of daily life. It has been suggested that such motor tasks as finger and/or foot tapping are not

complicated enough to fully test the motor performance system, and thus give valid insights into asymmetrical motor performance interference (Whitall, 1996). A recent study by Dromey and Benson (2003) utilized a nut and bolt assembly task. The researchers still suggested that even this comparatively sophisticated task may not be sufficiently complex to fully tax the motor processing system. Few studies utilize motor tasks that can translate into meaningful everyday motor movement.

Speech tasks employed in research have varied in structure and complexity from uttering a single nonsense syllable to picture description or spontaneous monologue. The more complex speech tasks are difficult to control for detailed measurement. Repeating a single syllable with no meaning may not provide valid information about how the speech motor system operates in meaningful conversation. In the research literature, speech accuracy has often been measured by the production of audibly recognizable errors (Kosaka, Hiscock, Strauss, Wada, & Purves, 1993). The performance of the articulatory movements required for speech is complex and intricate. Overt speech errors represent a severe disturbance in the process of speech generation, and it is possible that more subtle variations in performance go undetected when speech sounds normal to a listener.

More detailed measures of speech performance are necessary in order to provide a clearer picture of the impact of an additional task on speech motor performance (Chang & Hammond, 1987). Recent studies have utilized more subtle measurements of speech motor production, such as the STI (Bates, 2003; Dromey & Benson, 2003). These studies have determined that differences in speech production can be found even when perceptual errors are not observed. Dromey and Benson (2003) found a significant decrease in the consistency of motor speech gestures when participants were

simultaneously performing a language task of generating verbs from nouns. They also found that lip displacement and velocity were reduced in speech that was produced simultaneously with motor tasks. The increased sensitivity of measures like the STI provides greater insight into subtle changes in speech in a dual task situation. This allows researchers to identify interference where none might be suspected if overt speech errors were the only evidence for interference.

Much of the research to date has focused on quantifying the accuracy of only one task in concurrent task paradigms. The other task, often referred to as a “distracter task,” is often not subjected to rigorous measurement. A recent study by Dromey and Bates (in press) determined that there is a bidirectional influence between tasks performed concurrently. Rather than a task simply being affected by the performance of another simultaneous task, a dynamic interaction occurs in which each task affects and is affected by the other. The observation of this bidirectional influence may shed valuable light on the subject of concurrent task performance.

The present study continues the work initiated by Dromey and Benson (2003) and Bates (2003) to better understand the patterns of interference seen in dual task performance. Building upon the foundation of earlier research, this study utilizes more challenging tasks, more subtle performance measures, and recognition of bidirectional influences to develop a clearer picture of how simultaneous tasks may impact each other. It is hypothesized that performance asymmetries in the right versus the left hand will be seen when speech and language tasks are used to challenge one hemisphere more than the other. Specifically, it is anticipated that right hand performance will interfere more with speech and language tasks, because they both rely on left hemisphere processing.



## Method

### *Participants*

For the current study 10 males (mean age 22.8 years) and 10 females (mean age 21.0 years) participated. They were native English speakers with no history of speech, language, or hearing disorders, as determined by self-report. Each participant completed the Edinburgh Handedness Inventory to verify right-handed dominance (See Appendix A). Each participant passed a hearing screening at 25 dB HL at 500, 1000, 2000, and 4000 Hz bilaterally and gave written consent prior to participation in the study.

### *Instruments*

Each participant was seated comfortably in a sound booth. Lip and jaw movements were measured with a head-mounted strain gauge system developed by Barlow, Cole, and Abbs (1983). The cantilever beams were attached using double-sided tape to the skin adjacent to the midpoint of the vermilion border of the upper and lower lips and to the skin under the chin to track the lip and jaw movements of the speaker. The three kinematic signals were digitized with a Windaq 720 (DATAQ Instruments) analog/digital converter at 1 kHz. A sound level meter (Larson Davis 712) was placed 100 cm in front of the participant to record vocal intensity. A microphone was attached to the strain gauge system to collect the speech signal, which was digitized at 25 kHz after being low pass filtered (Frequency Devices 9002) at 12 kHz. A 76 cm high table was placed in front of the participant for performance of the Purdue Pegboard test.

The Purdue Pegboard test consists of a 1 by 2 foot rectangular wooden board with 25 peg holes on the right and left side. Indentations on the upper portion of the pegboard form cups to hold the pegs and washers. The Purdue Pegboard test was originally

developed to screen individuals for employment in positions requiring manual dexterity. It has also been used in studies of brain lesion location (Costa, Vaughan, Levita, & Farber 1963) and to identify children with learning disabilities (Gardner & Broman, 1979). Norms have also been developed for several populations including adults (Tiffin & Asher, 1948) and adolescents (Siegel & Hirschorn, 1958).

The Edinburgh Handedness Inventory was used to determine that participants were dominantly right-handed. The Edinburgh Handedness Inventory is a 10 question self-report on the following 10 activities: writing, drawing, cutting with scissors, brushing teeth, throwing, using a knife (without a fork), using a spoon, upper hand when using a broom, striking a match, and opening a lid. Participants were required to have a strong right-handed preference to qualify for inclusion in the study.

#### *Procedure*

Each participant completed a training session a day before the study in order to become familiar with the experimental tasks and equipment. Additional practice was provided immediately prior to the experiment to ensure understanding and minimize any learning effects that might contaminate the recorded data.

Participants performed several different tasks. The order of both isolated and dual tasks was fully randomized, since all participants had been familiarized with test procedures. Experimental tasks included the speech motor, verbal fluency, and manual motor tasks (one trial per hand) performed in isolation, as well as the motor task with one trial per hand performed simultaneously with either the speech motor or verbal fluency task. The experimental conditions were preceded by instructions and examples of the required tasks. Speech was recorded during all trials.

*Speech motor.* Participants produced the phrase “Peter Piper picked a peck of pickled peppers.” The phrase was chosen because it contains a number of bilabial closures to facilitate straightforward kinematic segmentation and because it is a moderately challenging speech task. This phrase was repeated each time the speaker heard a beep, for a total of 14 tokens. Lip and jaw movements were recorded under each condition that involved speaking the target phrase.

*Language.* Verbal fluency was assessed following the methodology used in the Controlled One Word Association Test (COWAT; Benton & Hamsher, 1976). Verbal fluency is used as a test of language development and spontaneous language generation skills (Riva, Nichelli, & Devoti, 2000). The increased complexity of lexical searching for phonologically based word lists as opposed to semantically based verbal fluency tasks prompted its use in this study. Participants were given a letter of the alphabet and asked to list as many words as possible beginning with that letter (excluding proper nouns and repeated root words with varied suffixes). Participants were given 60 seconds to produce as many words as possible. The number of responses was measured from the microphone recording.

*Manual motor.* Each participant completed the motor skills task once with each hand. Instructions involved presenting the individual with the materials that he or she would be using (metal pegs, washers, and the pegboard), and a demonstration of how the pegs and washers were to be placed in the holes. Participants were instructed to select only one item at a time. If the participant dropped either item, he or she was instructed to disregard it and continue the task. The participants were told that they would hear a beep to signal that they should begin placing the items in the pegboard. They were to continue

this until they heard a second beep, 60 seconds later. The Purdue Pegboard originally required three 30-second trials. Trial time was extended to coincide with the verbal fluency task requirements in the present study.

### *Data Analysis*

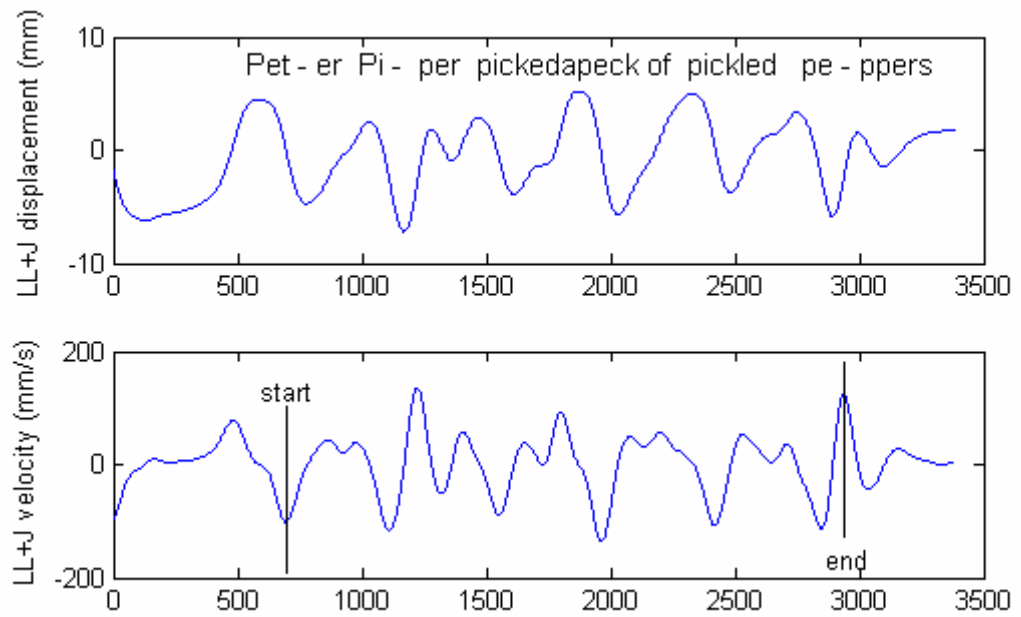
Performance measures were made for each task in both the isolated and the concurrent conditions. The Windaq lip and jaw recordings were exported as binary files and analyzed with custom Matlab applications. The kinematic signals were low pass filtered at 10 Hz in Matlab prior to analysis. The three movement channels were displayed on a computer monitor for segmentation and semi-automated measurement of the dependent variables. The audio signal served as a guide during the kinematic analysis, but was not analyzed acoustically. The specific movement measures are described below. The lower lip signal represented the combined movement of the lower lip and jaw, and was not decoupled. All kinematic analyses were completed on 10 repetitions (the final 10 of the 14 productions) of the phrase “Peter Piper picked a peck of pickled peppers.” Productions with any audible speech errors were excluded from the analysis and replaced with normally produced tokens from the first four that were spoken. An error was defined as either a perceptible difference in articulation or prosody or a visible kinematic difference between a given token and the other tokens produced in the same set.

*Utterance duration.* The time between the peak velocity for the first opening movement (release of the “p” in the word “Peter”) and the peak velocity of the last closing movement (closure of the last “p” in the word “pepper”) defined the utterance duration (See Figure 1). This measure was made in order to determine whether performing a concurrent task would influence the rate of speech production.

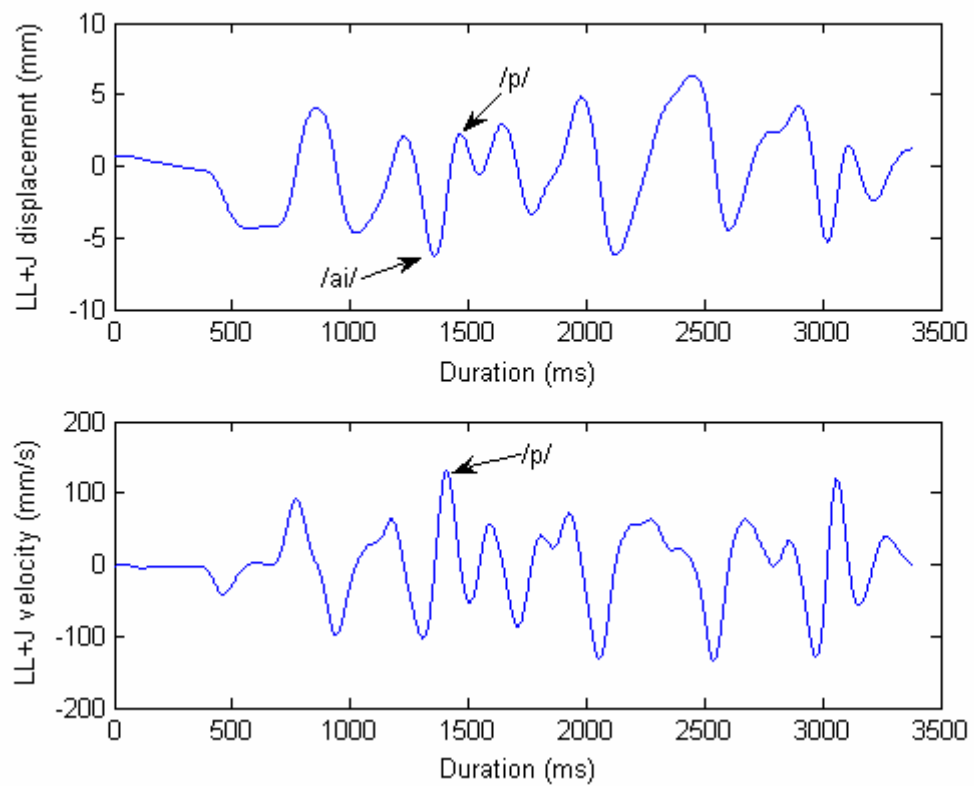
*Displacement.* Displacement was measured for the closing movement from the /aI/ to the /p/ in “Piper.” See Figure 2 for details of the signal segmentation.

*Velocity.* Peak velocity was also measured for closure into the second /p/ in the word “Piper.” Velocity was derived from the displacement signal using a two-point difference method. The displacement and velocity measures allow for evaluation of the effect of dual task performance on the amplitude of the selected articulatory gestures. Point measures have been used in previous kinematic studies to examine the influence of variables such as vocal effort (Dromey, 2000), rate (Dromey & Ramig, 1998a), and inspiratory level (Dromey & Ramig, 1998b).

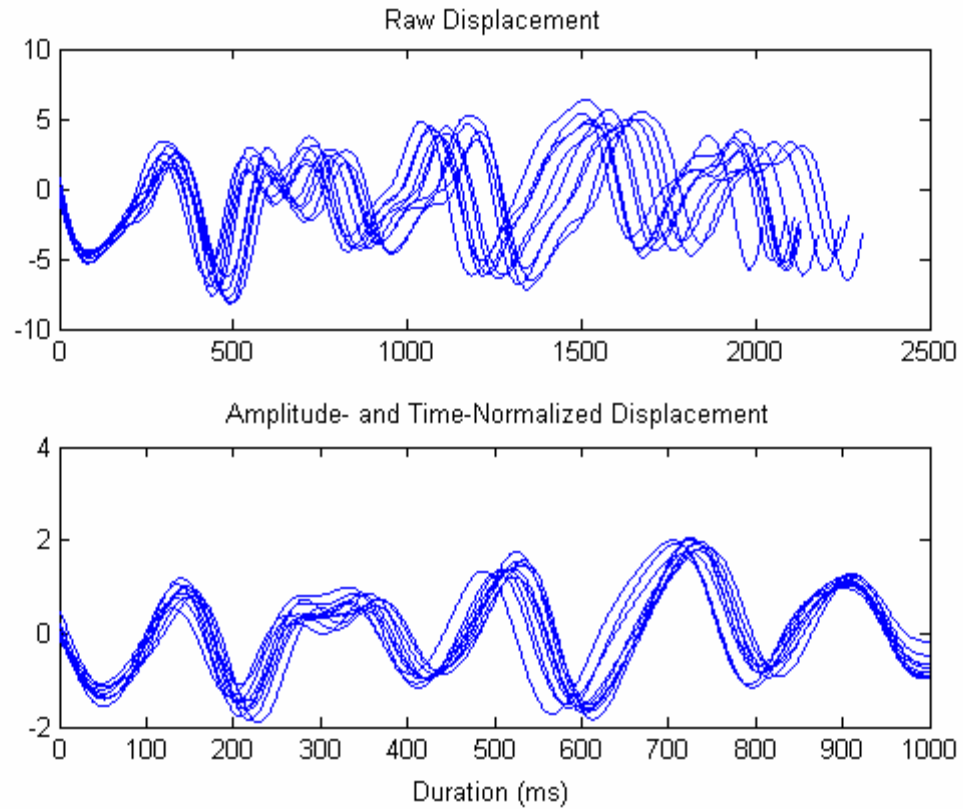
*STI for the lower lip-plus-jaw.* The Spatiotemporal Index (STI) was also calculated. The STI is a speech motor measurement that has been used in more recent studies (Bates, 2003; Dromey & Benson 2003; Smith, et al., 1995) to measure differences in the consistency of speech movements across repetitions. The entire utterance (as segmented in ‘Duration’ above) was used for this measure. The waveforms were normalized for time and amplitude (See Figure 3). Amplitude normalization was accomplished by subtracting the mean and dividing by the standard deviation of each displacement. Fourier analysis and re-synthesis was used to compute a linear interpolation used for time normalization. As no two repetitions of the same stimulus are identical in duration and mean amplitude, normalizing the waveform allows for the statistical analysis of multiple productions using the same number of sample points (Smith, et al. 1995). The standard deviation of 50 equally spaced points along the normalized waveform was calculated and summed to yield the STI (Kleinow & Smith, 2000). The STI thus serves as a measure of consistency of speech movements over



*Figure 1.* Displacement (upper pane) and velocity (lower pane) of the lower lip during one token of the target utterance. The kinematic record used for analysis was segmented from the peak velocity of the opening movement of /p/ in Peter to the peak closing velocity of the second /p/ in peppers.



*Figure 2.* Point measures for displacement (upper pane) from the /ai/ to the final /p/ in Piper, and peak velocity (lower pane) of the closing gesture of the final /p/ in Piper.



*Figure 3.* Displacement records (upper pane) of the lower lip and jaw for 10 repetitions of the speech task of one participant. The corresponding amplitude- and time-normalized displacement record (lower pane) for the same 10 repetitions.



multiple repetitions. Previous studies utilizing this technique have found decreased consistency when speech is produced concurrently with another task (Dromey & Bates, in press; Dromey & Benson, 2003).

*Sound pressure level (SPL).* The mean value of the SPL between the starting and ending points was calculated from the digitized signal from the sound level meter. Dromey and Bates (in press) found varied increases in SPL in a dual task situation. The measure was used in this study to determine whether vocal effort would increase or decrease when speakers divided their attention with a motor task. Because SPL changes have been associated with changes in respiratory, laryngeal, and articulatory behavior (Dromey & Ramig, 1998a; Dromey & Ramig, 1998b; Dromey, Ramig, & Johnson, 1995; Dromey, Stathopoulos, & Sapienza, 1992), it was reasoned that SPL could also be influenced by concurrent task performance.

*Language.* Verbal fluency was measured by calculating the total number of correct words by subtracting the number of false starts, non-words, and repeated words from the total number of productions during the 60 second trial.

*Motor.* The manual motor task was scored by verbal report from the participants as to the number of pegs and washers they had placed during the 60 second trial. Video recordings were reviewed to confirm score accuracy.

Dependent measures were analyzed in a series of repeated measure ANOVA procedures. The main independent variable was the experimental condition under which the tasks were performed, either isolated or concurrently. Gender was included as a between-subjects factor. Previous work (Dromey & Benson, 2003) found differences in the degree to which men and women are affected by dual task performance.

## Results

The kinematic and intensity data analysis is based on comparing the concurrent task conditions with the speech-only condition. The descriptive statistics for the dependent variables for each speech related condition were calculated and summarized in Table 1. Repeated measures ANOVA results and between-condition contrasts for speech kinematic measures are summarized in Table 2. The descriptive statistics and repeated measures ANOVA contrasts for performance on the language task in isolated and concurrent conditions are summarized in Table 3. Table 4 summarizes the descriptive statistics and the results of repeated measures ANOVA for motor performance. Only those results that were found to reach statistical significance will be reported here in detail.

### *Speech*

Articulatory displacement of the lower lip + jaw decreased significantly in the concurrent motor right and motor left conditions. Right handed motor activity had a greater effect upon motor speech performance than did the left hand. The peak velocity was also significantly affected in both the motor right and motor left conditions. Right-handed performance resulted in greater decreases in lip velocity than did left-handed performance. The spatiotemporal index (STI) increased significantly in left-handed motor performance. Sound pressure level (SPL) increased significantly in the concurrent condition for both the right and the left hand.

### *Language*

The verbal fluency scores decreased significantly when performed concurrently with the left-handed motor task but not for the concurrent right-handed condition.

Table 1

*Descriptive Statistics for the Kinematic and Sound Pressure Measures in the Speech-Only, Speech with Motor Right, and Speech with Motor Left Conditions*

Condition	Speech-Only		Speech + Motor Right		Speech + Motor Left	
Variable	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Duration (ms)	1809.98	169.43	1757.33	191.92	1783.84	195.82
LL+J Displacement (mm)	8.01	2.30	6.98	1.79	7.16	2.00
LL+J Velocity (mm/s)	135.98	33.23	122.72	28.95	125.57	32.41
STI LL+J	13.22	2.68	13.97	2.69	15.07	3.91
dB SPL at 100 cm	56.88	2.29	58.63	2.16	58.55	2.39

*Note:* Duration = utterance duration; LL = lower lip; J = jaw; STI = spatiotemporal index.

Table 2

*Repeated Measures ANOVA and Within Subjects Contrasts for the Kinematic and Sound Pressure Measures between the Speech Only and Concurrent Task Conditions*

Condition	Overall ANOVA		Speech + Motor Right		Speech + Motor Left	
	<i>F</i> -ratio	<i>p</i> -value	<i>F</i> -ratio	<i>p</i> -value	<i>F</i> -ratio	<i>p</i> -value
Duration <sup>a</sup>	3.313	.059	6.006	.024	1.150	.297
LL+J Displacement	8.305	.001	15.269	.001**	14.297	.010*
LL+J Velocity <sup>b</sup>	6.054	.009	10.724	.004*	4.623	.045*
STI LL + J	3.945	.028	1.318	.265	7.485	.013*
dB SPL <sup>c</sup>	31.794	<.001	37.623	<.001**	32.910	<.001**

*Note.* Degrees of freedom are 2, 38 for ANOVA main, 1,19 for ANOVA contrasts for all tests except as noted below. Duration = utterance duration; LL = lower lip; J = jaw; STI = spatiotemporal index. <sup>abc</sup>Mauchly's Test of Sphericity violated. Huynh-Feldt degrees of freedom = <sup>a</sup>1.635, 31.059, <sup>b</sup>1.663, 31.596, <sup>c</sup>1.398, 26.571.

\**p* < .05. \*\**p* < .01.

Table 3

*Descriptive Statistics (Number of Words Produced) and Repeated Measure ANOVA Results for Language comparing the Isolated and Concurrent Conditions*

Condition	Mean	SD	F-ratio	p-value
Language Isolated	17.10	4.36	--	--
Language + Motor Right	15.85	4.23	2.654	.120
Language + Motor Left	15.85	3.86	4.507	.047*

\* $p < .05$ .

Table 4

*Descriptive Statistics (Number of Pegboard Items Placed) and Repeated Measures ANOVA Results for Motor Right and Motor Left Performance in the Isolated and Concurrent Conditions*

Condition	Mean	SD	F-ratio	p-value
Motor Right Isolated	34.50	3.09	--	--
Motor Right + Speech	34.40	4.16	.046	.832
Motor Right + Language	31.85	4.39	18.209	<.001**
Motor Left Isolated	32.05	3.46	--	--
Motor Left + Speech	32.20	4.26	.064	.804
Motor Left + Language	29.80	3.92	13.020	.002**

*Note.* Degrees of freedom are 1, 18 for all tests.

\*\* $p < .01$ .

*Motor*

Pegboard scores decreased significantly when this task was performed concurrently with the language task, but not with the speech task. Right handed performance decreased more than left handed performance.

## Discussion

The aim of this study was to extend the previous work of Dromey and Bates (in press) and Dromey and Benson (2003) to better evaluate the bidirectional influence of manual motor activity on speech and language performance. Right- and left-handed performance was measured in order to determine whether there would be support for the functional distance hypothesis (Kinsbourne & Hicks, 1978).

### *Speech*

*Displacement.* Several aspects of speech kinematics were impacted by the concurrent completion of the manual motor task. A decline in the articulatory displacement of the lips occurred in the concurrent task condition, when compared with the isolated speech task. This result is consistent with the findings of Dromey and Benson (2003). They suggested that decreased displacement could be the result of increased attentional demands when both tasks were performed simultaneously. Nelson (as cited in Lindblom, 1990) suggested that speech is similar to other motor production, in that it follows a pattern designed to minimize energy expenditure. Speech effort may fall along a continuum for a given motor pattern. At one extreme, a great amount of energy is expended and articulatory gestures are exaggerated. At the other extreme a minimal amount of energy is utilized and motor speech movements are minimized. The point along the continuum at which speech is produced depends on the auditory feedback the speaker receives regarding the acceptability of the message. Thus, as attention is needed to complete another concurrent task, effort may be sacrificed in speech production without directly affecting intelligibility.

*Velocity.* The reduced peak velocity is consistent with the results of Dromey and



Benson (2003), who suggested that this might be due to decreased vocal effort in a concurrent task condition. The increased demands of concurrent task performance may have decreased the amount of effort dedicated to the speech task. Peak velocity has been used as a general measure of energy expended in speech production (Lindblom, 1990). Decreased peak velocity may indicate along with decreased articulatory displacement that less energy and effort are being expended in speech production during concurrent task conditions.

In both of these kinematic measures, statistically significant differences were found between isolated and concurrent performance. However, right-handed activity led to greater speech changes than did left-handed activity. These results are in accordance with those proposed by the functional distance hypothesis. This hypothesis predicted that tasks drawing upon neural resources that are closer in proximity to one another would be more susceptible to interference in dual task situations. For this study the functional distance hypothesis would predict that there would be greater interference in concurrent conditions targeting the right hand and speech and language performance than concurrent conditions with the left hand. This prediction is based on the lateralization of speech and language control to the left hemisphere.

*STI.* STI increased significantly for concurrent left-handed performance compared with the speech-only condition. STI is generally considered to be a measure of the consistency of speech movements across repetitions of an utterance. An increase in the STI may be reflective of the nature of the dual task condition, and represents a qualitatively different change from the reduction in displacement and velocity. The consistency and stability of articulatory patterns may require similar neural resources to

those used in the coordination of motor performance, resources that are under greater demand when using the non-dominant hand. A study by Maner, Smith, and Grayson, (2000) indicated that increased STI measures might indicate that speech motor patterns are more unstable as the complexity of the tasks increases. This may indicate that the “demands” of left-handed fine motor performance were greater than the demands for the equivalent right-handed activity.

When contrasting left- and right-handed motor tasks, support for a strict interpretation of the functional distance hypothesis is reduced. Performance of a fine motor task with the non-dominant hand may call upon more extensive neural resources. Dominant hand performance might be more reliant on previously established motor patterns that are easily modified to adapt to the current task.

Research using lesion studies to identify cortical areas responsible for various tasks have found that a strict contralateral regulation of motor performance is not always present. In a study by Haaland, Harrington, and Knight (2000) MRI scans were performed on stroke patients with ideomotor limb apraxia to ascertain lesion site. The researchers found the lesions to be lateralized to the left hemisphere. They concluded that “the middle frontal gyrus and intraparietal sulcus region . . . are critical for control of complex goal-directed movements” such as the reaching and grasping movements used in their study (pg. 2306).

Another study found that when stimulation was applied to the left premotor cortex, delays were found in selecting motor representations (Schluter, Rushworth, Passingham, & Mills, 1998). This suggests increased involvement of the left hemisphere in motor movement tasks which, when combined with the unfamiliarity of left-handed

fine motor performance, may have required more attentional resources than were available. It appears that more complex motor performance involves the use neural resources located in the left hemisphere. Because the STI is a measurement of the consistency of complex movement patterning, it may be sensitive to the use of these resources in the left hemisphere.

*SPL.* The significant increase in SPL from the isolated to concurrent condition has previously been associated with an increase in effort to complete speech tasks (Dromey & Bates, in press). The increase in SPL in the absence of similar increases in velocity and displacement was an unexpected result. Research concerning the impact of SPL on speech kinematics has associated increased SPL with larger kinematic movements. However, these studies involve the instructed and voluntary increase of intensity in speech. It appears that there are different underlying mechanisms in the association between SPL and speech kinematic activity in voluntary and involuntary conditions.

### *Language*

The significant decline in language scores when performed concurrently with the left-handed motor task fails to conform to our predictions based on the functional distance hypothesis, which would have suggested more interference with the right hand. A study performed by Leslie, Davidson, and Batey (1985) examined unimanual and bimanual performance on the Purdue Pegboard Test in disordered and normal readers. Males diagnosed with dyslexia (a naming deficit) between the ages of 9 and 12 were found to perform significantly more poorly on the left-handed unimanual task than the right-handed unimanual task. The authors speculated that the “left hand performance may be affected by left hemisphere processing either through commissural pathways or

through direct ipsilateral connections” (pg. 367). With the demonstrated bidirectional influence between performance of a unimanual motor task and a verbal fluency task, it could be speculated that the neural resources responsible for the differences in motor performance for boys with dyslexia may be similar to those that were overtaxed in the concurrent left-handed manual and verbal fluency performance.

Leslie et al. (1985) suggested that their results indicated a difficulty in transferring motor plans from the left hemisphere, where fine motor dexterity and planned sequential action are initiated, to the right hemisphere for execution. A similar phenomenon may account for the difference seen in language performance when paired with left-handed motor activity. Another possible explanation is that the available attentional resources were simply exceeded by the demands of the verbal fluency task and the continued novelty of the non-dominant hand’s fine motor demands.

### *Motor*

Adding the demands of the language task to the manual motor activity resulted in a significant decline in manual motor performance. The absence of a similar effect in the manual motor and speech conditions is noteworthy. This finding may be explained in several ways. The first is that the language task simply challenged the system in a way that the speech task did not. The speech task used in this study required the continuous production of a practiced speech motor plan. However, the language task required that participants search their lexicon for appropriate responses and then generate different speech motor patterns to produce the selected words.

A second possibility is that the motor task in this study might not have been measured in a sufficiently subtle way to effectively assess interference. The findings of

other studies that speech tasks disrupt motor performance such as finger tapping seem to indicate that the motor task should have been sufficiently challenging. A study by McFarland, Ashton, Rich, and Donald (1989) found greater right than left hand disruption in rapid finger tapping while completing speech tasks (reading a list of words).

However, a study by Seth-Smith et al. (1989) required the non-verbal generation of language (just silently generating a monologue rather than verbalizing it). This study found no significant impact on finger tapping from concurrent language demands. The use of a language task that require the online generation of language as well as the motor speech production of that language may be sufficiently difficult to impact the concurrent performance of motor tasks. Research by Dromey and Bates (in press) and Dromey and Benson (2003) indicates that speech and language have different impacts upon other concurrent tasks. It appears that in some instances the demand of either a speech or a language task may be insufficient to cause concurrent task interference. However, the combination of the demands of a language task and a speech task may be sufficiently demanding to interfere with concurrent task performance. In this study it remains unclear as to what portion of the observed interference results from the speech motor output of the list of new words, and what portion of observed interference might be the result of language generation.

The overall results of the present study suggest that a strict interpretation of the functional distance hypothesis may not be the best predictor of dual task interference. While certain results supported the hypothesis, others did not. The cognitive resources used to complete a task may be much more complex than can be accounted for in a simple lateralization model. Even a task that draws heavily upon the resources of a

specific hemisphere is often complex enough to utilize many areas of the brain. As a result, unexpected areas of interference result. While a modified version of the functional distance hypothesis may still explain some aspects of dual task interference, the original version of this theory (LaBarba et al. 1987) appears insufficient to explain the results seen in this and other studies .

*Directions for Future Research.*

The findings of this study indicate the need for further research into dual task performance. While many others have been able to document a difference in right-handed versus left-handed motor performance in the concurrent task condition (Chang & Hammond, 1987; Seth-Smith et al., 1989; Simon & Sussman, 1987), the current study was not able to find distinct differences in the manual motor scores of the participants. Instead this study was able to document changes in speech such as decreased displacement and velocity and increased STI measures. Also, declines in language performance due to unimanual motor performance were observed. In future studies, the use of more detailed measurements of the motor task may allow for more subtle differences in motor performance to be seen as a consequence of the speech task. Such measures may include the rate and placement attempts of the pegs and washers. Placement time might be compared between conditions, a measure not done in the present study. Additional tasks such as block manipulation tasks may be better able to test object placement and manipulation in terms of accuracy and the manual force used to complete the task. This may provide additional insight into the inconsistent findings of right-handed versus left-handed motor disruption during speech and or language tasks.

The cumulative results of these studies indicate that there might be additional

information to be gathered concerning the interaction between motor, speech, and language performance. Our results indicate that speech tasks have different impacts upon concurrent task performance than do language tasks. Additional research should focus on better quantifying the different demands that speech tasks have versus language tasks. According to the findings of Dromey and Benson (2003), care should be taken to account for the difference between the impact of speech upon motor tasks and the impact of language upon motor tasks. While it is difficult to separate language and speech production in research settings, it appears that each has specific and unique demands. The nature of the current language task attempted to minimize the demands of speech production, but these minimized demands can not be ruled out as having influence upon the overall complexity of the task.

Another direction for future research would be to perform a similar study with left-handed individuals to evaluate any differences found in that population. This could lead to more useful inferences about whether interference is based solely upon hand dominance, or whether processing demands also factor into task interference. Also, this research may be extended to examine the influence of dual task demands upon individuals with communication deficits. This will provide valuable insight into how to modify and address treatment tasks to more effectively treat communication disorders.

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## Appendix A

## EDINBURGH HANDEDNESS INVENTORY

Name \_\_\_\_\_

Date of Birth \_\_\_\_\_

Sex \_\_\_\_\_

Have you ever had a tendency toward left-handedness?

Yes
-----

No
----

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column*. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put ++*. If in any case you are really indifferent *put + in both columns*.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand-preference is wanted is indicated in the brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		R	L
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		

L.Q.	
------	--

Leave these spaces empty

DECILE	
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*Appendix B***Consent to be a Research Participant**Introduction

You are invited to participate in a research study, designed to help us learn more about the simultaneous performance of speech, language, and hand movement tasks. Your participation will provide valuable information about how the brain processes the demands placed on it and prioritizes performance. This study is being conducted by Erin Hamblin, a graduate student at Brigham Young University under the supervision of Dr. Christopher Dromey, an associate professor in the Audiology and Speech-Language Pathology Department. You were selected for participation because you are a right handed native English speaker with no history of speech, language, or hearing disorders.

Procedures

You will be asked to participate in two 1-hour sessions on separate days. You will be seated in a sound booth and complete a fine motor task (placing pegs in holes on a board), a speech task (repeating a sentence), and a language task (generating lists of words). You will perform each task on its own, and then in different combinations. Measurement of your performance will involve the use of audio and video recordings. A head-mounted strain gauge system will also be used to measure your lip and jaw movement patterns while you speak. The first session is intended to let you practice the experimental tasks before we make recordings of your performance. The second session is for recording data. Each session will take approximately 1 hour.

Risks/Benefits

There are no known risks associated with participation in this study. All the equipment we use in this study has been used here and elsewhere without any problems. There are no direct benefits to you from your participation in this study. However, the results will provide valuable information about dual task performance or a person's ability to perform two tasks concurrently. This may eventually contribute to advances in our treatment of disordered communication.

Confidentiality

There will be no reference to your identification in paper or electronic records at any point during the research. An identification number will be used to organize the data we collect.

Participation

Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to standing with the university.

Questions about the Research

If you have any questions about this study, you may contact Christopher Dromey at (801)422-6461.

Questions about your Rights as a Research Participant

If you have questions you do not feel comfortable asking the researcher, you may contact Dr. Renea Beckstrand, IRB Chair, 422-3873, 422 SWKT, renea\_beckstrand@byu.edu.

Signatures

I have read the above and understand what is involved in participating in this study. My questions have been answered and I have been offered a copy of this form for my

records. I understand that I may withdraw my participation at any time. I agree to participate in this study.

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date