2008

The Effects of Divided Attention on Speech Motor, Verbal Fluency, and Manual Task Performance

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Original Publication Citation

Dromey, C. & Shim, E. (2008). The effects of divided attention on speech motor, verbal fluency, and manual task performance. Journal of Speech, Language, and Hearing Research, 51, 1171-1182.

The effects of divided attention on speech motor, verbal fluency, and manual task performance

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Running head: Divided attention

ABSTRACT

Purpose: The goal of this study was to evaluate aspects of the functional distance hypothesis, which predicts that tasks regulated by brain networks in closer anatomic proximity will interfere more with each other than tasks controlled by spatially distant regions. Speech, verbal fluency, and manual motor tasks were examined to ascertain whether right-handed activity would interfere more with speech and language performance, because of the presumed greater demands on the left hemisphere.

Method: 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 concurrently.

Results: Speech kinematic data showed that during concurrent performance of manual tasks, lip displacement and peak velocity decreased, while sound pressure level increased. Spatiotemporal variability increased when the non-dominant hand was used for a motor task. Manual motor scores significantly decreased when concurrently performed with the verbal fluency task, but not with sentence repetition.

Conclusions: These findings suggest that the control of concurrent tasks may be more complex than is predicted by the functional distance hypothesis.

INTRODUCTION

More often than not, people tend to speak and listen while involved in other activities. As one author has noted, "Situations that require divided attention are the rule, not the exception" (Lane, 1982, p.121). This means that the brain must be able to regulate more than one process at a time, which can result in measurable changes in performance when compared with distraction-free speech (Dromey & Bates, 2005; Dromey & Benson, 2003). Researchers in the field of cognitive psychology have examined so-called *dual task* or *divided attention* phenomena for several decades (Allport, Antonis, & Reynolds, 1972; Chang & Hammond, 1987; Hiscock, Kinsbourne, Samuels, & Krause, 1985; Ho, Iansek, & Bradshaw, 2002; Pashler & Johnston, 1998; Wickens, 1984), and a number of theories have been developed to account for the observed findings.

For two simultaneous tasks, if performance on one increases, it typically declines for the other. A plot of these results may show a relatively smooth "trade-off" curve depicting this inverse relationship. Those who subscribe to so-called *capacity theories* interpret these results to support the sharing of attentional resources in a graded fashion. Some have suggested that the brain has multiple processors that can be assigned to different types of incoming stimuli. If two tasks depend on the same resources, the interference that results leads to a performance decrease for either or both tasks (Leclercq, 2002). If different processing resources are used for each task, they do not interfere with each other, and dual task performance can be as good as when either task is completed alone (Allport et al., 1972).

Time-sharing models account for such dual-task interference by suggesting a series of rapid and smooth transitions between the two tasks (Wickens, 1984). If we preferentially target one of two tasks, we may simply be attending to one for a greater length of time before switching attention to the other. A limitation of either the capacity or time-sharing models is that they do not provide any detail about the potential mechanisms involved – how the processing resources are shared – and also cannot account for all of the experimental observations (Leclercq, 2002).

Most models of cognitive processing in dual task situations seek to explain the results in purely psychological terms. A different type of theory developed by Kinsbourne and colleagues suggested a neurophysiological explanation for dual task interference. The *functional distance hypothesis* (Kinsbourne & Hicks, 1978) is intuitively appealing because cortical mapping research has identified specific areas of the brain that are more active when individuals perform a given task. Kinsbourne and Hicks suggested that the degree of interference during the performance of multiple tasks is inversely related to the distance between cerebral networks which are activated for those tasks. Therefore, two tasks utilizing relatively separate areas of the brain will show a decreased level of interference. But when two tasks utilize neural structures that lie in close proximity to each other, there would be an increased risk of cross-talk between the active neurons, observed behaviorally as a decline in performance in one or both tasks.

According to the functional distance hypothesis, differences between right- and left-sided limb performance would be anticipated in concurrent tasks involving speech and language because the left hemisphere motor strip and speech/language areas of the brain are anatomically close. 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. However, the notion that the left hemisphere is almost solely responsible for speech and language processing may be too simplistic. Recent neuroimaging studies have revealed important right hemisphere contributions. For example, one study revealed that the right hemisphere may be particularly active in verb generation tasks where semantically related responses are required (Chiarello, Kacinik, Shears, Arambel, Halderman et al., 2006). Other experiments have revealed right cortical involvement in inner speech, where individuals are required to imagine speaking an utterance instead of actually saying the words (Fujimaki, Hayakawa, Matani, & Okabe, 2004; Kato, Muramatsu, Kato, Shintani, & Kashima, 2007). Additional reports have noted right hemisphere involvement in natural language processing (Jung-Beeman, 2005; Lindell, 2006). Such findings suggest that an overloading of the left hemisphere for speech/language and concurrent right-handed tasks, as would be predicted by the functional distance hypothesis, might not actually occur.

Several dual task studies have found the predicted effect when comparing left- or right-sided motor movement with speech and language tasks (Chang & Hammond, 1987; Hiscock et al., 1985; Seth-Smith, Ashton, & McFarland, 1989). These studies found that finger-tapping performance for each hand declined in a dual task situation. In most, but not all cases (e.g., Simon & Sussman, 1987), performance declined more for the right hand than for the left. Seth-Smith et al. (1989) found a significant increase in the deviation from tapping rate with the right hand when a story was retold aloud. The lack of similar lateralized interference for the silent story retelling suggested that the motor speech component of vocalization may have played a role in the observed interference. Simon and Sussman (1987) found a greater change in finger tapping rate for the dominant hand, regardless of whether the participant was right- or left-handed. They suggested that the more skilled hand with its naturally higher performance might be more susceptible to changes during concurrent task performance. They also suggested that ipsilateral control of the left hand could have contributed to the findings.

Several studies have provided evidence that the left hemisphere contributes to the control of more than just the contralateral muscles. Haaland and colleagues' work suggests that the left hemisphere is involved in regulating goal-directed movements with either hand (Haaland, Harrington, & Knight, 2000), and that it appears specialized for controlling dynamic aspects of trajectory as opposed to static position (Haaland, Prestopnik, Knight, & Lee, 2004). These findings corroborate those of an earlier study that suggested a dominant role of the left premotor cortex in the rapid selection of actions by either hand (Schluter, Rushworth, Passingham, & Mills, 1998). Taken together, these studies suggest that the functional distance hypothesis prediction of a simple right hand disadvantage during concurrent speech and language tasks may be too crude.

A challenge in the study of concurrent task performance is the potential complication of learning effects. As a task is repeated, the initial performance accuracy may be poor, but it improves with practice. This is true for both simple and complex tasks, such as reading while writing from dictation (Spelke, Hirst, & Neisser, 1976). Some have suggested that practiced tasks can gradually become more automatic and thus require less attention as they are repeated (Leclercq, 2002). The performance of a novel task initially requires a greater depth of processing, with an evaluation 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 simultaneous task, which may lead to performance improvements.

Many studies have employed simple motor tasks because they can be easily quantified (e.g., repeated rapid finger tapping), but it is difficult to extrapolate from these to typical human behavior. Some speech tasks are designed to more realistically simulate normal conditions (i.e. spontaneous monologues) but performance during these tasks is difficult to quantify in a straightforward way. The goal is to select tasks that can be measured objectively, yet attempt to challenge the participants in ways that resemble everyday situations. Instead of simple syllable repetition, recent studies (Dromey & Bates, 2005; Dromey & Benson, 2003) have utilized finer grained measurements of speech motor production during the repetition of whole phrases, such as the spatiotemporal index, or STI, which is a measure of the variability in speech movements across multiple repetitions (Smith, Goffman, Zelaznik, Ying, & McGillem, 1995). These studies have determined that subtle 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 patterns 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 insight into imperceptible but potentially interesting 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 generally not subjected to rigorous measurement. A recent study by Dromey and Bates (2005) documented bidirectional influences between tasks performed concurrently, similar to the mutual influences reported by Chang and Hammond (1987). 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.

Our previous experiments (Dromey & Bates, 2005; Dromey & Benson, 2003) did not examine differences between left- or right-handed performance. In the 2003 study, the motor task consisted of assembling nuts, bolts, and washers, which naturally required the actions of both hands. However, performance on this task was not quantified – it only served to distract the participant while speaking. The 2005 investigation involved skilled hand movements, but only with the right hand. One purpose of the present study was to examine aspects of the functional distance hypothesis by extending the findings from these two previous experiments to the left and right hands. The functional distance hypothesis would predict that right-hand performance would interfere more with speech and language tasks, because they both rely on left hemisphere processing. This hypothesis is clearly limited by the findings of previously discussed neuroimaging studies that both hemispheres play a role in language processing, and that some aspects of both left- and right-handed movements rely on left hemisphere control. Nevertheless, the current study was undertaken to evaluate whether behavioral measures would reveal left/right asymmetries in the interactions of concurrent communication and manual tasks. Separate tasks were selected to evaluate speech versus language activity, in combination with fine motor control of either hand.

METHOD

Participants

Ten males (mean age 22.8 years) and 10 females (mean age 21.0 years) participated in the experiment. They were right-handed native speakers of American English, who reported no history of speech, language, or hearing disorders. Each participant passed a hearing screening at 25 dB HL at 500, 1000, 2000, and 4000 Hz bilaterally and gave written consent to participate in the study, which was approved by the university institutional review board.

Instruments

Each participant was seated comfortably in a sound booth. Lip and jaw movements were measured with a head-mounted strain gauge system (Barlow, Cole, & Abbs, 1983). The cantilever beams were attached using double-sided tape to the skin adjacent to the midpoint of the vermillion 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 (Tiffin, 1948) consists of a 25 by 50 cm 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.

The Edinburgh Handedness Inventory (Oldfield, 1971) was used to determine that participants were dominantly right-handed. The inventory is a 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. On the Edinburgh scale, a score of 100 reflects full right-hand dominance. The mean score for the participants in the present study was 91.0 (SD = 7.9).

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 occur during data collection.

Participants performed several different tasks. The order of both isolated and dual tasks was fully randomized. The experiment included 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 familiar but 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.

Verbal fluency. The methodology from the Controlled One Word Association Test (Benton & Hamsher, 1976) was used to assess verbal fluency. The increased challenge of lexical searching for phonologically-based word lists as opposed to semantically-based items 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 test originally required three 30-second trials. Trial time was adjusted 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 lip and jaw recordings were 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. This combined signal was used for the kinematic variables in the present report, which will hereafter be referred to as lower lip measures. In the present study, no measures were extracted from the jaw or upper lip signals. 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."

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 as the distance moved by the lower lip during the closing movement from the maximal opening for /ɑI/ to the closure for /p/ in “Piper.” See Figure 1 for details of the point measure location.

Velocity. Peak velocity was also measured for closure into the second /p/ in the word “Piper”. The velocity signal was derived from the displacement record by differentiation in Matlab. The displacement and velocity measures allowed an evaluation of the effect of dual task performance on the scaling of the selected articulatory gestures. Such point measures – based on a single gesture from an utterance – have been used in previous studies as a reflection of the magnitude and speed of articulatory movements in response to changes in vocal effort or speech rate (Dromey & Ramig, 1998a), inspiratory level (Dromey & Ramig, 1998b), interventional strategies in dysarthria (Dromey, 2000), as well as during dual task performance (Dromey & Bates, 2005; Dromey & Benson, 2003). Because such point measures are necessarily limited to a single gesture, they allow only a narrow observation window of kinematic activity. Therefore, the STI was also calculated from an analysis of the entire movement record for each utterance.

STI for the lower lip. The 10 segmented displacement waveforms (see ‘Utterance Duration’ for the start and end points) were normalized for time and amplitude. 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. The standard deviation of 50 equally spaced points along the normalized waveform was calculated and summed to yield the STI (Smith et al., 1995). The STI thus serves as a measure of consistency of speech movements over multiple repetitions, with a smaller number reflecting lower variability.

Sound pressure level (SPL). The mean value of the SPL between the starting and ending segmentation points in the recorded utterance was calculated from the digitized signal from the sound level meter. The measure was used in this study to determine whether vocal effort would increase or decrease when speakers were required to divide their attention with a motor task.

Verbal fluency. This variable 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.

The 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 in isolation or simultaneously with another task. Speaker sex was also included as a between-subjects factor in the analysis, because previous work (Dromey & Benson, 2003) has shown differences in the degree to which men and women are affected by concurrent task performance. Effect size was calculated with the partial eta squared statistic (η^2). Because the numeric results were computed by the Matlab algorithms, the same kinematic records would yield identical output values, and thus data re-measurement to quantify reliability of these variables was not undertaken. A re-count of 20% of the verbal fluency data revealed this measure to fluctuate less than 1% across judges.

RESULTS

The kinematic and intensity data analysis was 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 are summarized in Table 1 and Figure 2. Repeated measures ANOVA results and concurrent between-condition contrasts for speech kinematic measures are summarized in Table 2. The descriptive statistics for motor performance are presented in Table 3 and Figure 3, and the ANOVA and contrast results for these tasks are reported in Table 4. Only those results that were found to reach statistical significance will be reported here in detail. Note that the *p*-values were not adjusted for the fact that 7 ANOVA tests were performed. The reader is encouraged to consider this when evaluating the results. Recent reports have cautioned against the blanket application of alpha level adjustments (O'Keefe, 2003; Tutzauer, 2003) and the associated risk of increasing Type II error rates. No interactions were found with speaker sex; therefore, all data are reported for male and female participants combined.

Speech

Compared to the speech-only condition, the displacement of the lower lip decreased significantly in the concurrent left- and right-handed pegboard conditions. The peak velocity also significantly decreased for concurrent task performance with each hand. The spatiotemporal index (STI) increased significantly when participants concurrently performed the left-handed pegboard task. Sound pressure level (SPL) increased significantly in the concurrent pegboard task for both the right and the left hand.

Motor

Pegboard scores decreased significantly when this task was performed using the left or the right hand concurrently with the verbal fluency task, but not with the speech task.

DISCUSSION

The aim of this study was to extend the previous work of Dromey and Benson (2003) and Dromey and Bates (2005) to better understand potential interactions between manual motor activity and speech or 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), which would predict stronger interference between speech or language tasks with concurrent right-handed activity.

Speech

Displacement. A decline in the displacement of the lower lip occurred for the concurrent conditions, when compared with the isolated speech task. This result is consistent with the findings of Dromey and Benson (2003), who suggested that decreased displacement could be the result of increased attentional demands when both tasks were performed simultaneously. 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 utterance or individual. At one extreme, a great amount of energy is expended and articulatory gestures are exaggerated. At the other, a minimal amount of energy is utilized and speech movements are smaller. In typical communication, the point along the continuum at which speech is produced depends in large part on the auditory feedback the speaker receives regarding the acceptability of the message. The present tasks were performed outside of an everyday communication context, and thus other factors may have been involved. However, it could be speculated that as attention is channeled toward the completion of the concurrent task, the amount of energy available to dedicate to speech production may be sacrificed without directly affecting intelligibility.

Velocity. The reduced peak velocity for the concurrent manual tasks is consistent with the results of Dromey and Benson (2003), and parallels the displacement results. 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 is being allocated to speech production during concurrent task conditions than when speech is produced alone. The concept of effort has been addressed in previous experiments, but it remains a difficult phenomenon to quantify. There is no objective metric of how hard a speaker is working to produce an utterance, although studies relying on a participant's own sense of constant effort have utilized measures of force production during fatigue experiments, leading to speculation about declining central nervous system drive to motor neuron pools (Solomon, Robin, Mitchinson, VanDaele, & Luschei, 1996). In the current context, it could be speculated that the when speakers were required to distribute their available attention to more than a single task, speech motor execution was scaled down, even as the total effort required for the combined tasks may have exceeded the expenditure for speech alone. Although these modest kinematic changes did not lead to perceptible changes in speech, and thus may not have any functional relevance, they offer an insight into subtle alterations in the motor control of speech when another task is performed concurrently.

In both displacement and velocity, statistically significant differences were found between isolated speech and concurrent manual conditions. However, right-handed activity led to marginally greater effect sizes for speech changes than did left-handed activity. These results would be consistent with the predictions of the functional distance hypothesis (Kinsbourne & Hicks, 1978), which predicts 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 prediction would be for greater interference in concurrent conditions targeting the right hand and speech or language performance. However, the modest differences in effect size between the left and right handed performance do not lend particularly convincing support to the functional distance hypothesis.

STI. This measure increased significantly for concurrent left-handed performance compared with the speech-only condition. STI quantifies the consistency of speech movements across repetitions of an utterance. An increase in this index is reflective of a different kind of kinematic change than is seen in the reduced displacement and velocity measures, which represent a change in movement scaling. The STI does not separate spatial from temporal movement differences across repetitions, and for this reason has drawn criticism that it may be too broad a measure to provide specific details about patterns of motor control, especially since it involves linear normalization which cannot adequately capture nonlinear rate-related changes in speech production (Lucero, Munhall, Gracco, & Ramsay, 1997). In spite of these limitations, the STI has revealed evidence of subtle changes in speech movements in a number of previous studies (Dromey, 2000; Dromey & Bates, 2005; Dromey & Benson, 2003; Dromey, Reese, & Howey, 2007; Kleinow, Smith, & Ramig, 2001; Smith et al., 1995; Wohlert & Smith, 1998). It is recognized that the STI cannot be unambiguously interpreted as a measure of interference when two tasks are performed concurrently. However, in the present study, it could be cautiously speculated that the consistency and stability of articulatory patterns may require similar neural resources to those used in the coordination of manual motor performance - resources that are under greater demand when using the non-dominant hand. A study by Maner, Smith, and Grayson (2000) suggested 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 overall attentional demands of left-handed fine motor performance were greater than the demands for the equivalent right-handed activity. Dominant hand performance might be more reliant on previously established motor patterns that are easily modified to adapt to the current task. It is possible that use of the non-dominant hand for the pegboard task entailed motor learning that remained incomplete, even after the practice sessions that the participants engaged in prior to data collection. This could have resulted in lower levels of automaticity, which would demand greater attention than a task performed with the dominant hand. Future studies of left-handed individuals would be needed to allow more confident inferences about hand dominance in these and similar tasks.

Lesion studies have revealed that the regulation of motor performance is not always organized in a strictly contralateral way. A study that examined MRI or CT scans of patients with ideomotor limb apraxia (Haaland et al., 2000) showed the lesions to be lateralized to the left hemisphere. However, the damage affected skilled movements with either hand. The authors concluded, “While the specific processes subserved by the left hemisphere are uncertain, the left premotor cortex appears to be involved in the selection of movements of either hand” (p. 2312). Therefore, unfamiliar left-handed fine motor activity, such as participants performed in the present study, may be at least as likely as right-handed demands to interfere with speech or language processing. Recent work with left- and right-hemisphere damaged individuals by Haaland and colleagues (Haaland et al., 2004) has suggested that the left hemisphere may regulate dynamic aspects of movement trajectories, whereas the right may be more involved in control of hand position. These findings suggest that further work to examine kinematic details of manual activity is warranted in studies designed to evaluate issues relating to hemispheric localization.

Further support for this notion comes from a study which revealed that when transcranial magnetic stimulation was applied to the left premotor cortex, delays were found in selecting motor actions with either hand (Schluter et al., 1998). This again suggests involvement of the left hemisphere in both ipsi- and contralateral motor tasks. In the present study, the combination of left hemisphere movement regulation with the unfamiliarity of left-handed fine motor performance, may have required more attentional resources than were available. 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, in contrast to the simpler scaling measures of displacement and velocity.

SPL. The significant increase in SPL from the isolated to the concurrent conditions has previously been suggested to reflect an increase in overall effort to complete the task (Dromey & Bates, 2005). However, it was not expected that SPL would increase while velocity and displacement decreased. Previous studies have documented larger and faster movements with louder speech (Dromey, 2000; Dromey & Ramig, 1998a; Dromey, Ramig, & Johnson, 1995). However, these studies involved deliberate increases in vocal effort, whereas no loudness instructions were given in the present study. It appears that there are different underlying mechanisms in the association between SPL and speech kinematic activity in deliberate versus involuntary loudness changes.

Recent studies by Huber and colleagues have investigated the effects on respiratory and articulatory kinematic behavior of eliciting louder speech in several different ways (Huber, 2007; Huber & Chandrasekaran, 2006; Huber, Chandrasekaran, & Wolstencroft, 2005). They found that when speakers increased their vocal output with feedback from a sound level meter, or by doubling their perceived loudness, or via the Lombard effect, the responses differed depending on the way louder speech was elicited. In the present study, the speakers were not asked to be louder, and thus the previously reported upward scaling of speech movements (Dromey & Ramig, 1998a; Schulman, 1989) might not naturally follow. It could be speculated that the demands of concurrent task performance increased the psychological stress level of the speakers, which may have influenced the degree of glottal adduction, which has been associated with higher intensity in some speakers (Stathopoulos & Sapienza, 1993). However, without either electromyographic or electroglottographic evidence of laryngeal adjustments, it is not possible to draw any clear inferences about such mechanisms from the present data.

Motor

Adding the demands of the verbal fluency task to the manual motor activity resulted in a significant decline in the number of pegs placed. The absence of a similar effect in the pegboard and speech conditions is noteworthy. It is possible that this language generation task challenged the speakers in a way that phrase repetition did not. Although it was motorically complex, the Peter Piper tongue-twister was simply repeated, and replaying the same ‘motor score’ (Kent, Adams, & Turner, 1996) may not have been as demanding as the retrieval of phonologically associated items from a speaker’s lexicon. A second possibility is that the motor task in this study might not have been measured in a sufficiently subtle way to detect interference during concurrent phrase repetition. Other studies involving simple finger tapping have found these movements to be impacted by speech tasks (Chang & Hammond, 1987; Friedman, Polson, & Dafoe, 1988; Hiscock et al., 1985; Smith, McFarland, & Weber, 1986). No detailed analysis was undertaken of the hand movements that were made by the participants in the present study, and it is possible that the count of items placed in the pegboard may have not been sensitive to more subtle motor differences.

We readily acknowledge that while the current experimental conditions were labeled as being *speech* or *language* tasks, neither could be considered 'pure,' because the verbal fluency words were spoken aloud, and the repeated tongue-twister was a linguistically conventional utterance. Our previous work (Dromey & Bates, 2005; Dromey & Benson, 2003) has shown that such speech- and language-oriented tasks can have different effects on other concurrent activities. But it remains unclear what portion of the observed interference results from the speech motor output of the list of new words, and what portion might result from language generation demands. Because speech and language performance cannot be isolated from each other in spoken language, it may not be possible to fully determine the contribution of each component. Nevertheless, the conditions for the present study were selected to at least focus more toward motoric complexity in the tongue twister, and toward linguistic challenge in the verbal fluency task, and in spite of their limitations, have uncovered some interesting differences.

In summary, the results of the present study lend extremely limited support to the functional distance hypothesis, and suggest that it may not be the best predictor of dual task interference. 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 regions of the brain.

Directions for Future Research.

In future studies, the use of more detailed measurements of the motor task may allow more subtle differences in motor performance to be seen when individuals perform concurrent tasks that make demands on speech motor or linguistic processing. Such work could include measurements of hand trajectories or force generation by the fingers. Finally, this research should be extended to examine the influence of dual task demands on individuals with speech and/or language deficits. This could provide valuable insights into how to modify therapy techniques to more effectively treat communication disorders in realistic contexts. A recent report (Crosson, Moore, Gopinath, White, Wierenga et al., 2005) provided evidence that deliberate left-handed motor activity may facilitate neural recovery in individuals with non-fluent aphasia by 'priming' the contralateral cortex to assume language processing activity that has been lost after a stroke. These and other interactions between communicative and limb motor activity are deserving of further investigation.

AUTHOR NOTE

We express our appreciation to the speakers who gave of their time to participate in this study. Contact Author: Christopher Dromey, Ph.D., Department of Communication Disorders, 133 Taylor Building, Brigham Young University, Provo, UT 80602. dromey@byu.edu

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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	*M*	*SD*	*M*	*SD*	*M*	*SD*
Duration (ms)	1809.98	169.43	1757.33	191.92	1783.84	195.82
LL Displacement (mm)	8.01	2.30	6.98	1.79	7.16	2.00
LL Velocity (mm/s)	135.98	33.23	122.72	28.95	125.57	32.41
STI LL	13.22	2.68	13.97	2.69	15.07	3.91
dB SPL at 100 cm	68.88	2.29	70.63	2.16	70.55	2.39

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

Table 2. Repeated measures ANOVA and effect size results across all conditions and also for 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		
Variable	*F*-ratio	*p*-value	η^2	*F*-ratio	*p*-value	η^2	*F*-ratio	*p*-value	η^2
Duration[a]	3.313	.059	.148	6.006	.024*	.240	1.150	.297	.057
LL Disp	8.305	.001**	.304	15.269	.001**	.446	8.300	.010*	.304
LL Vel[b]	6.054	.009**	.242	10.724	.004*	.361	4.623	.045*	.196
STI LL	3.945	.028*	.172	1.318	.265	.065	7.485	.013*	.283
dB SPL[c]	31.794	<.001**	.626	37.623	<.001**	.664	32.910	<.001**	.634

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; Disp. = displacement; Vel = peak velocity; STI = spatiotemporal index. [abc] Mauchly's Test of Sphericity violated. Huynh-Feldt degrees of freedom = [a]1.635, 31.059, [b]1.663, 31.596, [c]1.398, 26.571.

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

Table 3. Descriptive statistics (number of pegboard items placed) and for motor right and motor left performance in the isolated and concurrent conditions.

Condition	Mean	SD
Motor Right Isolated	34.50	3.09
Motor Right + Speech	34.40	4.16
Motor Right + Verbal Fluency	31.85	4.39
Motor Left Isolated	32.05	3.46
Motor Left + Speech	32.20	4.26
Motor Left + Verbal Fluency	29.80	3.92

Table 4. Repeated measures ANOVA and effect size results across all conditions and also for within subjects contrasts for the manual task (pegboard) performance between the isolated task and concurrent speech or verbal fluency conditions.

	Overall ANOVA			Manual + Speech			Manual + Verbal Fluency		
Condition	*F*-ratio	*p*-value	η^2	*F*-ratio	*p*-value	η^2	*F*-ratio	*p*-value	η^2
Right hand	14.236	<.001**	.428	.046	.832	.002	18.209	<.001**	.489
Left hand	8.290	.001**	.304	.064	.804	.003	13.020	.002**	.407

Note. Degrees of freedom are 2, 38 for ANOVA main, 1,19 for ANOVA contrasts.

*$p < .05$. **$p < .01$.

FIGURE CAPTION

Figure 1. Displacement (upper panel) and velocity (lower panel) 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 (start) to the peak closing velocity of the second /p/ in peppers (end). The arrows mark the displacement and velocity peaks selected for the point measures.

Figure 2. Means and 95% confidence intervals for the kinematic and sound pressure measures in the speech-only, speech with motor right, and speech with motor left conditions.

Figure 3. Means and 95% confidence intervals for the number of pegboard items placed for motor right and motor left performance in the isolated and concurrent conditions.

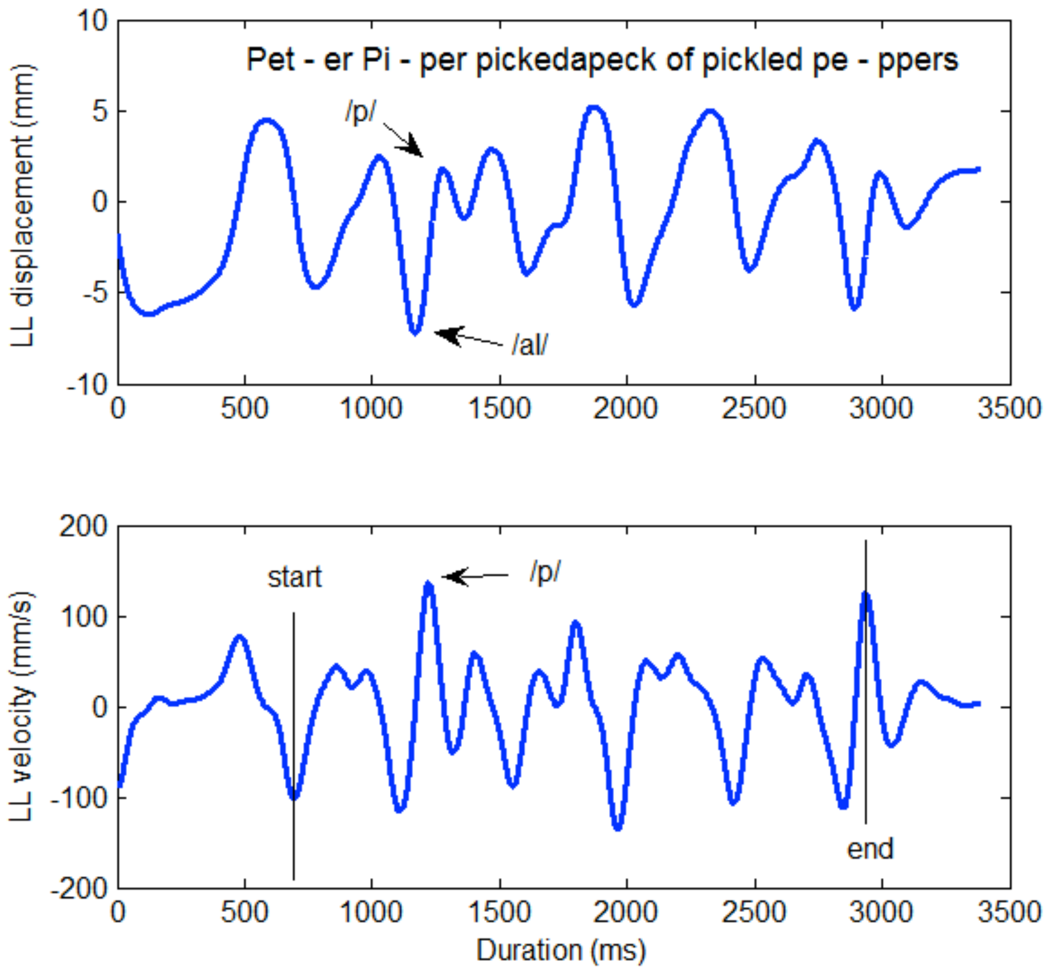
Pet - er Pi - per pickedapeck of pickled pe - ppers
/p/
/al/
LL displacement (mm)
10
5
0
-5
-10
0
500
1000
1500
2000
2500
3000
3500
LL velocity (mm/s)
200
100
0
-100
-200
start
/p/
end
Duration (ms)

Figure 1.

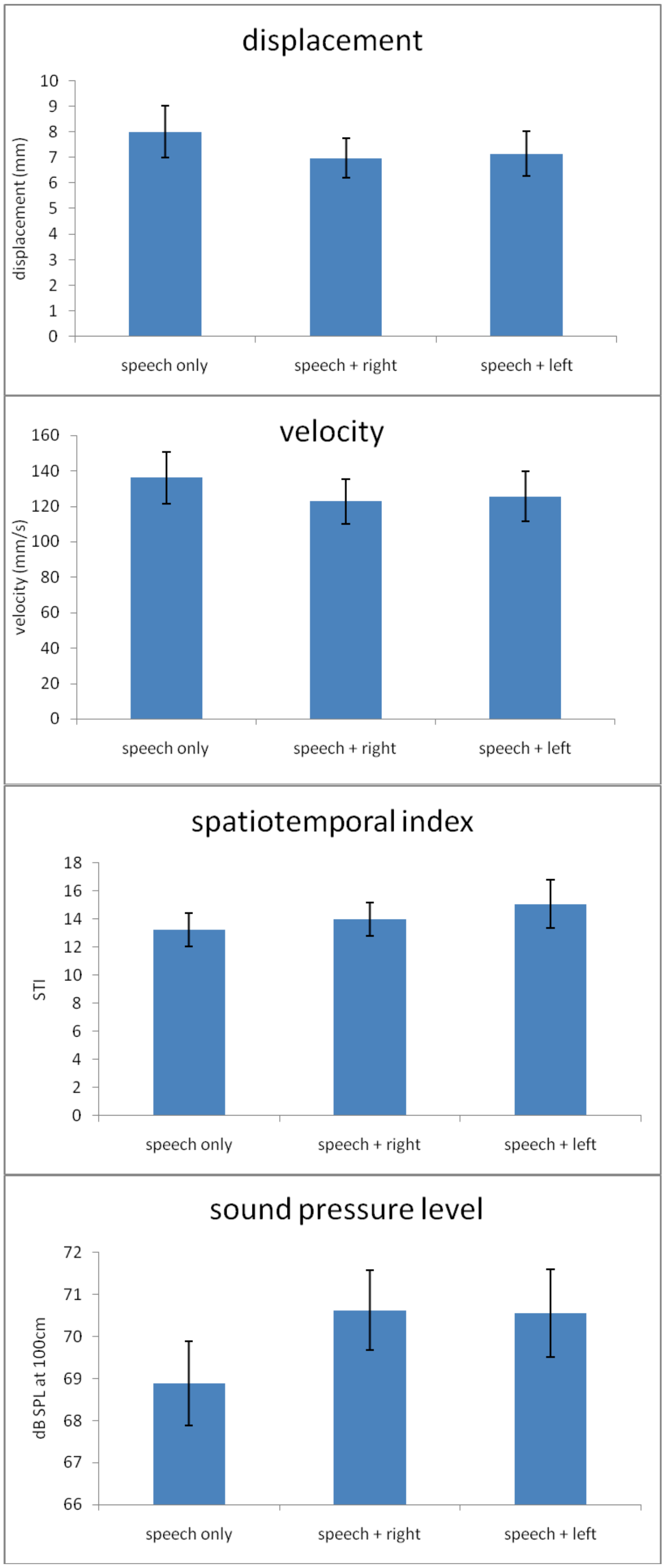
displacement
displacement (mm)
10
9
8
7
6
5
4
3
2
1
0
speech only
speech + right
speech + left
velocity
velocity (mm/s)
160
140
120
100
80
60
40
20
0
speech only
speech + right
speech + left
spatiotemporal index
STI
18
16
14
12
10
8
6
4
2
0
speech only
speech + right
speech + left
sound pressure level
dB SPL at 100cm
72
71
70
69
68
67
66
speech only
speech + right
speech + left

Figure 2.

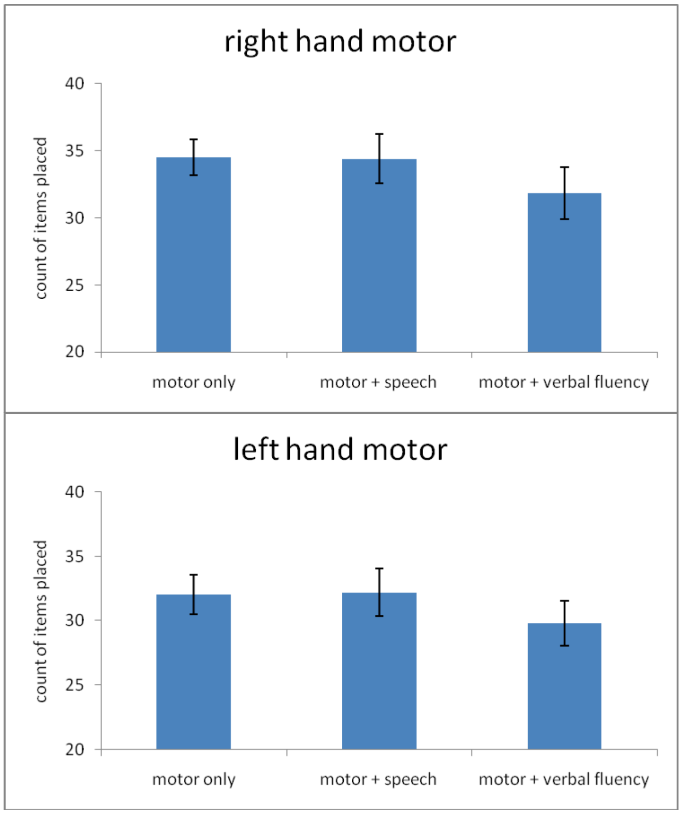
right hand motor
40
35
30
25
20
count of items placed
motor only
motor + speech
motor + verbal fluency
left hand motor
40
35
30
25
20
count of items placed
motor only
motor + speech
motor + verbal fluency

Figure 3.