Interference Between Speaking and Computer Tasks

in Younger and Older Adults

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

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This study examined the effects of computer tasks on speech acoustic measures and the effects of speaking on computer task performance in 30 younger and 30 older adults. Participants completed a speech only task, two computer tasks, and simultaneous speaking and computer tasks. Stimulus sentences included the four corner vowels and two diphthongs embedded between voiceless consonants. Acoustic measures of speech included diphthong transition extent and rate as well as vowel space area (VSA) and vowel articulation index (VAI). A text formatting task included two levels of difficulty. A data entry task included sorting items from a shopping list into categories. Statistical analysis revealed that the dual-task conditions led to a significant decrease in diphthong formant transition extent and rate. Speaking while completing the computer tasks led to an increase in diphthong duration. There was also a significant decrease for VSA and VAI for each dual-task condition compared to speaking alone. Diphthong transition extent, diphthong duration, and VAI were higher in the older adult group. Performance on all computer tasks significantly decreased when simultaneously producing speech. Overall, the findings reveal significant bidirectional interference between concurrent speech and computer tasks. The results also suggest older adults have poorer performance in divided attention computer tasks. The older adult participants were found to speak with longer vowel durations and more expansive articulation than the younger adults. The findings from this study may pave the way for future clinical work that may result in assessment and treatment approaches involving divided attention scenarios.

Keywords: divided attention, acoustics, computer task, age, articulation, speech
ACKNOWLEDGMENTS

I would like to thank my husband, Ryan, for all his love and support throughout the thesis process. He has been endlessly encouraging of my education and comforted me through countless hours of research, writing, and other coursework. I could not have completed this thesis without his support. Additionally, I am grateful for countless other family members that supported me in times of stress and sent encouraging messages and love.

I would also like to thank my cohort members and professors for their love, friendship, support, and kindness carrying me through my thesis and education. I would especially like to thank my committee members Dr. Shawn Nissen and Dr. Dallin Bailey for their knowledgeable feedback, patience with the process, and passion for this research.

Finally, I would like to thank my thesis chair Dr. Christopher Dromey for his extreme patience and kindness. His knowledge and passion for speech language pathology has been invaluable in this research as he has instructed me through each step of the process. I could not have completed it without him and am very grateful for his endless support.
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DESCRIPTION OF THESIS STRUCTURE AND CONTENT

This thesis, Interference Between Speaking and Computer Tasks in Younger and Older Adults, is written in a hybrid format. The hybrid format brings together traditional thesis requirements with journal publication formats required for the field of Communication Disorders. The preliminary pages of the thesis reflect requirements for submission to Brigham Young University. The literature review is included in Appendix A, and Appendix B includes the consent/institutional review board approval letter.
Introduction

It is rare that people focus on only one task at a time. In a fast-paced world, most people complete multiple tasks simultaneously. Whether it is talking on the phone while driving to work, listening to music while cleaning the house, or doing homework while listening for a bus stop on the way home from school, attention must be divided among multiple tasks. It has been observed that, “situations that require divided attention are the rule, not the exception” (Dromey & Shim, 2008, p. 1171). Dividing attention requires executive function to manage attentional resources that are not endless; our capacity to attend has limits (McDowd, 2007). Previous research has found that if two tasks completed simultaneously exceed the limits of available capacity, performance in one or both tasks may decline (Dromey & Bates, 2005; Dromey & Simmons, 2019; McDowd, 2007). This is known as a dual-task cost (DTC; McDowd, 2007) or more commonly as interference (Bailey & Dromey, 2015).

Knowing that attention is a limited resource, many researchers have speculated about the potential mechanisms underlying dual task performance. Two main theories of attention have been commonly referenced: structural theories and capacity theories (Bailey & Dromey, 2015; Dromey & Shim, 2008; McDowd, 2007; Navon & Miller, 2002). Structural theories define attention as a single, serial processing system, meaning that only one thing can be processed at a time. This theory identifies interference as occurring at a “bottleneck” during a dual-task condition, where all the brain’s attentional resources are focused on a single task and cannot be shared with another. While this theory provides a simple explanation, dual-task interference does not simply adhere to these expectations. Previous findings report that the time to complete two concurrent tasks is typically shorter than the sum of the time to perform each separately, suggesting there may be a better explanation (Navon & Miller, 2002).
Another possible explanation of this phenomenon is found in capacity theories. These view attention as a resource with a limited capacity (Bailey & Dromey, 2015; Dromey & Shim, 2008; McDowd, 2007). Kahneman (1973) suggested that there is one single, undifferentiated resource that is used for all tasks. According to this theory, if two tasks are relying on the same resource, interference will occur, and performance will decrease in one or both tasks (Dromey & Shim, 2008). However, this theory does not explain why some combinations of tasks can be more easily completed simultaneously than others (McDowd, 2007). In contrast to Kahneman’s theory, another model was created by (Wickens, 1991). This theory suggests that attention relies on multiple, independent, multidimensional resources and that there are separate pools of resources for different types of cognitive processing (Dromey & Shim, 2008). Wickens (1991) suggested there are four different resource dimensions: modality (auditory, visual), processing stage (encoding, central processing, responding), information code (spatial, verbal) and response mode (manual, vocal; McDowd, 2007). According to this theory, tasks performed simultaneously will interfere with one another to the extent that each draw on the same resources as the other (McDowd, 2007). Conversely, if each task uses different resource pools, they will not interfere with each other, and there will be no dual task cost; performance will be as competent as when each task is completed in isolation (Dromey & Shim, 2008).

A further refinement of this theory is known as the functional distance hypothesis which suggests the degree of interference in divided attention tasks is related to the proximity of the cerebral networks activated during those tasks (Kinsbourne & Hicks, 1978). Evidence supporting this theory would reveal that two tasks relying on nearby areas of the brain would demonstrate increased interference and decreased performance in both tasks. Conversely, tasks using anatomically different areas of the brain would involve decreased interference and unchanged
performance in both tasks (Dromey & Shim, 2008). Dromey and Shim tested this hypothesis with an experiment in which left- and right-hand performance in dual-task conditions in right-handed participants was measured and compared for interference between speech, language, and motor tasks. The study showed participants to have greater interference when they used their non-dominant (left) hand while speaking, which did not provide clear support for the functional distance hypothesis (Dromey & Shim, 2008).

In the field of speech-language pathology, researchers are primarily interested in the effect of concurrent tasks on speech production. Conversations take place while a person is completing another attention demanding task. Speech therapy is typically completed in a quiet, distraction-free, clinic room as a personal one-on-one interaction between the client and the clinician. However, this is not always representative of speech production in daily life. Thus, there may be limits to the generalization of therapeutic progress from a controlled clinical environment to the busy setting of social interaction in daily life. An examination of the effects of divided attention on speech may provide insights that lead to changes in clinical environments and allow clinicians to provide naturalistic therapy that will more readily generalize to the typical multi-tasking environments encountered by individuals with communication disorders.

Previous research has examined the grammatical and linguistic effects of a dual-task condition on spoken language. Kemper et al. (2005) reported that individuals completing other tasks while speaking use a restricted speech register composed of shorter, less complex sentences when compared to their typical communication in a speech-only task condition. In a study targeting differences in fluency, grammatical complexity, and information content of adults while performing concurrent motor tasks, Kemper et al. studied 24 young and 24 older adults’ language samples through conversation questions in a speech only and dual-task condition.
involving everyday motor tasks (e.g., walking with a bag of groceries, up a flight of stairs). In the study, younger adults adopted a restricted speech register and older adults spoke with a slowed speech rate.

Kemper et al. (2011) also discovered that speakers’ performance in multiple concurrent tasks decreased when participants were engaged in speech motor planning. This interference was supported by the observation that speakers’ performance in an interfering task declined at the instance directly before a spoken utterance. In this study, 40 younger and 40 older adults were challenged with the divided attention task of tracking a moving target and responding orally to a verbal prompt. The study additionally revealed the participants used slowed speech with shorter and less grammatical and propositionally dense content (Kemper et al., 2011). It has also been found that speakers have an increased occurrence of filled pauses and repetitions in divided attention tasks. A study by Oomen and Postma in 2001 of the association between attention and disfluency analyzed the speech of 18 young adult participants in isolation and during a tactile-perception task of blindly exploring sand-paper figures and identifying the tactile object. They found increased pauses and sound, word, and phrase repetitions in the dual-task condition when compared to the speech-only condition for the majority of participants. These findings of decreased speaking rate, increased pauses and repetitions, and simplified grammatical content during dual-task conditions suggest an overall decreased ability to speak efficiently and perform routine tasks simultaneously.

Grammatical and linguistic measures reveal useful information about spoken language patterns during a selected task. However, they cannot reveal subtle speech production changes across conditions. Finer grained, acoustic and kinematic measures can identify these small changes to more fully understand the effects of divided attention on speech production. Using
these measurement methods, several studies by Dromey have analyzed divided attention tasks
effects on the articulation of typical speakers (Bailey & Dromey, 2015; Dromey & Bates, 2005;
Dromey & Shim, 2008). In Dromey and Bates’ 2005 study, they analyzed the effects of
simultaneous linguistic, cognitive, and visuomotor tasks on speech performance in 20 young
adults. During each of the assigned tasks, participants recited the target phrase, “Peter Piper
would probably pick apples.” The participants' lip and jaw movements were recorded and
analyzed lower lip and jaw displacement, velocity, and spatiotemporal index (a measure of
articulatory stability across repetitions). Utterance duration, sound pressure level, and upper and
lower lip correlation were also analyzed for each speech task. The linguistic task of correcting
sentences resulted in increased spatiotemporal variability of lip displacement and the motor task
led to more rapid speech with smaller lip displacement. This suggests the speakers generated
restricted movements during the dual-task condition, reflecting decreased articulatory
performance.

In Dromey and Shim’s 2008 study participants' lip displacement and peak velocity
decreased with divided attention tasks. Additionally, a significant increase in sound pressure
level (SPL) was found. In this study 20 participants completed a motor task of placing pegs and
washers on a pegboard and a verbal fluency task of listing as many words as possible beginning
with a given letter while completing a speech motor task of reciting the phrase, “Peter Piper
picked a peck of pickled peppers.” The observed increase in SPL and decrease in lip
displacement and velocity revealed the speakers used more effort to recite the phrase and with
less precision while simultaneously completing another task (Dromey & Shim, 2008). A similar
study using different speech stimuli revealed a significant increase in mean utterance duration
during the dual-task condition (Bailey & Dromey, 2015). In a recent study, Dromey and
Simmons (2019) analyzed the effects of a driving simulation task on acoustic speech performance during a monologue on a given topic. In this study of 30 men and 30 women, they discovered decreased performance on the driving simulation and speech performance during the dual-task condition for the majority of participants. The speakers demonstrated lower speaking time ratios and increased speed variability when challenged with divided attention tasks. These studies reveal that completing a simultaneous task during speech can have significant effects on speech motor performance as shown through the analysis of acoustics and kinematics.

Acoustic analysis of speech provides objective measures that can indirectly reflect how clearly a speaker is articulating. Individuals subconsciously adjust the rate, intensity, and clarity of their speech to meet the demands of a given situation. These adjustments allow the individual to produce an acoustic signal that is intelligible in a specific setting and environment (Whitfield et al., 2018). Specifically, spoken vowels have unique acoustic characteristics which are composed of multiple frequency components. These frequencies are produced by the larynx and filtered through the vocal tract to produce a wide variety of sounds. When certain frequencies are resonated through the vocal tract with higher concentrations of energy than others, the more prominent frequencies are known as formants (Dromey et al., 2021). Acoustic studies frequently analyze the first two formants of a given sound to identify the vocalic sound and use several metrics to reflect the articulatory effort used in producing the sound (Dromey et al., 2021).

Previous research has identified a strong association between acoustic measures and articulatory movements such as tongue advancement and labial protrusion during vowel production (Dromey et al., 2008). Particularly, the first formant (F1) of a sound is inversely related to the tongue height of the speaker when producing the vowel. Conversely, the second formant (F2) is directly related to tongue advancement (Dromey et al., 2021). Therefore, the first
and second formants of a sound have previously been used to calculate a vowel space area (VSA) metric to quantify the extent of tongue height and advancement from three or four vowels extracted from a speech recording (Whitfield et al., 2018). The authors of a recent study noted, “because the frequencies of F1 and F2 roughly relate to the size and shape of the cavities created by jaw opening and tongue position, VSA can be considered an acoustic proxy of kinematic placement of the articulators” (Caverlé & Vogel, 2020, p. 1436).

The current study will analyze the effects of dual-task conditions on similar acoustic measures of speech production. These measurements will provide valuable data pertaining to the articulatory production of each participant in both a speech only and divided attention task condition. These specific acoustic measures provide controlled and reliable measures of articulatory performance. The present study will use measurements such as vowel space area (VSA) and vowel articulation index (VAI; Roy et al., 2009) to analyze articulatory performance during speech production using formant analysis. These calculations reflect the extent of tongue height and advancement of a speaker during production of corner vowels /i/, /æ/, /u/, and /ɑ/.

Additionally, the study will involve calculations of transition extent, duration, and rate of diphthong transitions to measure how extensively the speaker is articulating during diphthong production. These specific and objective measurements can reveal subtle articulation changes that are not perceptible to a listener.

While analyzing the impact of divided attention on speech production, there are many factors to consider that have been found to influence an individual's ability to divide their attention, including chronological age, neurological status, fatigue, stress, practice, and attentional effort (McDowd, 2007). The current study will analyze the effects of age on divided attention and articulation performance. In one account, aging was defined as “the biological
process of growing old, regardless of chronological age” (Tremblay & Ross, 2007, p. 305). The process of aging affects individuals in different ways; however, there are general physiological, neurological, and physical changes that occur with age. Structural changes throughout the body include atrophy, dystrophy, edema, changes in elasticity, demyelination, neoplasm, and mutation. Due to these structural changes, older adults’ activities of daily life are typically associated with decreased accuracy, speed, range, endurance, coordination, stability, and strength when compared to younger adults (Zraick et al., 2006).

Aging has also been described as “a continuum of incremental changes leading to measurable, progressive decreases in basic functions within organ systems” (Zraick et al., 2006, p. 134). This decline in organ systems can lead to changes in body structure and composition, sensory perception, cardiovascular system, musculoskeletal system, and the neurological system (Zraick et al., 2006). The brain is a complex organ, and its function continues to slow with age. In fact, many studies have shown overall brain volume and gray matter volume to decrease with advancing age (Barnes, 2015; Beheshti et al., 2019; Fan et al., 2018). Due to these neurological changes in the aging brain, cognitive decline is one of the most common causes of disability among older adults. This especially pertains to processing speed, visuospatial skills, executive function, attention, and memory (Fan et al., 2018; Tremblay & Ross, 2007).

Consequently, as individuals experience many of the physical and mental changes of aging, distinct and measurable changes in speech have also been observed. Significant anatomical and physiological effects of aging can be detected in the respiratory, phonatory, supraglottal, and nervous systems (Zraick et al., 2006), all of which are heavily involved in speech. With regard to the respiratory system, Hoit and Hixon (1987) initially found and later confirmed (Hixon & Hoit, 2005) that elderly men and women used less efficient speech
breathing while reading when compared to younger adults. The study revealed larger lung volume excursions, increased frequency of inhalation, and increased air expenditure during non-voiced intervals of speech. Voice production also has been observed to change for both men and women throughout the lifespan. Speaking fundamental frequency in men lowers from young adulthood into middle age and then rises again into old age. In women, fundamental frequency remains consistent into middle age and then lowers and remains unchanged through old age (Zraick et al., 2006). Additionally, resonance characteristics of vocal quality have been observed in elderly individuals. Specifically, centralization of vowels has been found to frequently occur in older speakers. As a result, formant frequencies of vowels are observed to have significant differences in older and younger adults (Zraick et al., 2006). Kinematic studies have also revealed that lip muscle activity during speech declines with age (Zraick et al., 2006).

Many previous studies have demonstrated the effects of age on ability to perform divided attention tasks. These studies have consistently revealed that older adults have decreased ability to complete two tasks simultaneously (Kemper et al., 2005; Kemper et al., 2011; MacPherson, 2019). Specifically, older adults have been found to produce speech more slowly, with less articulatory precision, and with more breakdowns or errors than younger adults (MacPherson, 2019). It is hypothesized these outcomes are a product of cognitive changes across the lifespan including sensory changes, reductions in processing speed, and working memory limitations (Kemper et al., 2011.) Although speech intelligibility is not compromised with age, changes in speech motor control are significant and are often characterized by decreased fine motor control with increased cognitive load (MacPherson, 2019). Previous research has demonstrated age-related motor decline affects articulatory performance (Bailey & Dromey, 2015; Kemper et al.,
The current study will build upon these findings through analysis of the speech of younger and older adult participant groups across multiple dual-task conditions.

Previous studies have examined the effects of divided attention on speech production through grammatical, kinematic, and acoustic analysis. However, few have considered the effects of computer-based tasks on speech as reflected through the acoustic analysis of vowels and diphthongs, or how age affects the performance of concurrent cognitive and speech production tasks. The purpose of the current study is to analyze the bidirectional interference between speaking and using a computer in younger and older adults. Specifically, the current study will assess the impact on articulatory function as measured through changes in the first and second formants. It is hypothesized that performance will decrease for both speech and computer tasks when they are completed simultaneously. Additionally, it is hypothesized that performance will decrease more as the difficulty of the computer tasks increases. Finally, it is also hypothesized the older adults will demonstrate decreased performance on all tasks when compared to younger adults.

**Method**

**Participants**

Sixty adults will participate in the study. They will be divided into two age groups: 15 male and 15 female young adults (ages 18-30) and 15 male and 15 female older adults (ages 55+). All participants will be native English speakers and will have no history of speech, language, or hearing impairment. Each participant will pass a hearing screening bilaterally at 500, 1000, and 2000 Hz. The tone stimulus will be presented at 30 dB HL for the young adults and 40 dB HL for the older adults. Each participant will sign an informed consent form approved by the Institutional Review Board to participate in the study.
**Equipment**

Each participant will be seated in a single-walled sound attenuating booth to ensure an optimal environment for producing high-quality acoustic recordings. The participants will then be fitted with an AKG C420 (AKG Acoustics, 2003) head mounted microphone to record their speech. The microphone will be connected to a FocusRite Scarlett 2i2 USB analog to digital converter for recording to a desktop computer. A calibration vowel produced by the speaker for reference will be recorded and measured using a sound level meter placed 50 cm from the participant’s mouth to allow for accurate software measurements of speech intensity. The calibrated vowel will be used to correct the speech intensity during acoustic analysis of the microphone signal. The acoustic signal will be recorded using Adobe Audition software (Adobe Audition Team, 2019). The participants will complete the computer tasks on an Apple MacBook Air laptop inside the sound booth using Microsoft Word and Microsoft Excel with a USB plug-in mouse.

**Procedures**

Each participant will complete a speaking task and three computer tasks during a one-hour session. Each of the four tasks will be completed in isolation and each computer task will be completed again simultaneously with the speaking task. The order of the tasks will be randomized for each participant to avoid sequencing effects. While still randomized, the tasks in isolation will be performed before the tasks completed simultaneously. Each participant will be instructed through a practice of each task prior to experimental trials. During experimental trials, each task will be completed for 60 seconds, excluding the speaking task in isolation which will be completed for 30 seconds.
Tasks

The speaking task consisted of repeating the two sentences: “The thief hid his cash out of sight. They shout when the shot goes in the hoop.” The sentences were produced in an alternating order for the duration of the task. The participants were encouraged to speak at their normal speaking rate and intensity. The sentences were devised specifically for the purpose of the study to measure corner vowels and diphthongs in a CVC context. Therefore, the vowels and diphthongs in the sentences were placed with voiceless stops on either side for easier segmentation of the vowels during data analysis.

In a data entry computer task, the participants will be instructed to manually sort grocery items from a list into their correctly corresponding categories using Microsoft Excel. The grocery categories will consist of produce, dairy, baking supplies, meats, and freezer section. Shortcut features such as “copy” and “paste” will be prohibited throughout the task. The participants will also be informed the order of the items entered will not affect their performance score. The task will be completed as quickly and accurately as possible for the duration of 60 seconds. This task will be completed at random in isolation and simultaneously with the speaking task.

In a text formatting task, the participants will be instructed to manually edit words from a narrative passage. There will be two text formatting tasks presented, varying slightly in level of difficulty. The Level 1 task will require the participants to highlight each instance of the word “the” within the passage. The Level 2 task will require the participants to highlight each instance of the word “the” and underline each instance of the word “a” within the passage. Shortcuts such as “control-F(find)” and “control-U (underline)” will be prohibited throughout the task; participants will format the text using the toolbar buttons. For each task, the participant will have 60 seconds to complete it as quickly and accurately as possible. Each of the levels of the text
formatting task will be completed in isolation and simultaneously with the speaking task, with the order of these conditions being selected at random. Both the text formatting and data entry computer tasks will mostly be language oriented but may also include visual and motor involvement through visually scanning, moving the cursor, and selecting the highlight or underline function. While these tasks reflect linguistic based tasks, they may also indicate conclusions regarding divided attention during speech and cognitive and spatial tasks.

**Data Analysis**

Audio recordings were analyzed using the Praat (Version 6.2.14; Boersma & Weenink, 2022) software program. Praat was used to segment individual vowels from the repeated sentence stimuli. The vowels were embedded between two voiceless consonants and consisted of the corner vowels: /ɑ/, /ɪ/, /æ/, and /u/. The sentences also included the diphthongs /aɪ/ and /aʊ/. The vowels /ɪ/, /æ/, /aɪ/ are segmented from the words ‘thief’, ‘cash’, and ‘sight’ in the sentence, “The thief hid his cash out of sight.” The vowels /aʊ/, /ɑ/, and /u/ are segmented from the words ‘shout’, ‘shot’, and ‘hoop’ in the sentence, “They shout when the shot goes in the hoop.”

Following vowel segmentation, the formants of each vowel were computed. Praat calculated the values for F1 and F2 for 5 vowel productions for each task. These values were used to calculate:

**Vowel Space Area and Vowel Articulation Index**

The vowel space area (VSA) was calculated using the values of F1 and F2 for each repetition of corner values for each participant. F1 and F2 midpoint frequencies were plotted on an X-Y graph, where the corner vowels marked the corners of the vowel quadrilateral, and the area of the quadrilateral was measured with a custom MATLAB software (Version 2023a; Mathworks, 2023). Vowel articulation index (VAI) is based on proportions using points F1 and
F1 from each corner vowel through the equation \((F2\alpha + F2i + F1\alpha + F1\alpha) / (F2u + F2\alpha + F1i + F1u)\).

**Diphthong Measures**

Diphthong transition extent (DTE) is the measure change in frequency from the beginning of the diphthong to the end of the diphthong in both F1 and F2. Diphthong duration is the measure of length of time from the beginning of the diphthong production to the end of the diphthong production. Transition rate is calculated by dividing the transition extent by the duration of the diphthong. This equation reflects the rate at which they produced the diphthong from beginning to end.

The text formatting and data entry computer tasks were analyzed using Microsoft Word and Microsoft Excel software programs. Each completed task was carefully and precisely graded, and values were recorded to reflect performance. Participants' performance was measured through amount completed in a timely manner and accuracy of alterations to the documents. The following values were used to calculate these measures:

**The Efficiency and Accuracy of Highlighted Words**

The Level 1 and Level 2 text formatting tasks were analyzed for the number of occurrences of the word “the” highlighted correctly within the 60 second time window. They also were analyzed for the number of occurrences of the word “the” that should have been highlighted but were missed until the point of the last correctly highlighted word within the document. Additionally, the number of words that should not have been highlighted that were highlighted mistakenly during the text formatting tasks were calculated.
The Efficiency and Accuracy of Underlined Words

The number of occurrences of the word “a” that were underlined correctly within the 60 second time window was calculated for the Level 2 formatting tasks only. It was also analyzed for the number of occurrences of the word “a” that should have been underlined but were missed until the point of the last correctly underlined word within the document. Finally, the number of words that should not have been underlined that were underlined mistakenly was calculated for the Level 2 text formatting tasks.

The Efficiency and Accuracy of Sorted Words

The data entry task was analyzed for the number of words that were correctly sorted into their corresponding categories within the allotted 60-minute time frame. The number of words that were incorrectly sorted into the wrong semantic categories during completion of the task were also calculated. Finally, the number of words within the data entry task that were incorrectly spelled during completion of the task were analyzed.

Statistical Analysis

A linear mixed model analysis will be used to test for significant changes in the acoustic measures and computer task scores. Speaker sex, age group, and condition (single or dual task) will be fixed factors and individual speakers will be the random factor. Bonferroni-corrected contrasts will test for differences between conditions and speaker sex and group.

Results

The descriptive statistics and LMM results are presented in tables at the end of the thesis. Descriptive statistics are presented in Tables 1, 4, and 6. The results of linear mixed model testing are found in Tables 2, 3, 5, 7, and 8. Figures are also included after the Tables. Figures 1,
2, and 3 show /ai/ F2 change, rate, and duration across the conditions. Figures 3 and 4 reflect VSA and VAI across the conditions.

**Effects of Computer Tasks on Acoustic Measures**

Linear mixed model testing revealed a significant main effect of condition for /ai/ on F1 rate, F2 change, F2 rate, and duration. Comparison analysis revealed that all dual-task conditions led to a significant decrease in /ai/ F1 and F2 rate. The Level 1 text formatting task with speech was associated with a decrease in /ai/ F2 change. All conditions reflected an increase in /ai/ duration when compared to the speech only task condition. There was a significant main effect of condition for /au/ on F1 rate, F2 rate, and duration. Comparison analysis revealed that /au/ F1 and F2 rate significantly decreased and /au/ duration significantly increased for every dual-task condition compared to the speech only condition.

A significant main effect of condition on VSA and VAI was also revealed by the linear mixed model testing. Comparison analysis revealed a significant decrease for both VSA and VAI in each dual-task condition compared to the speech only condition. The analysis revealed a significant effect of age for /ai/ F2 change, /ai/ duration, /au/ F2 change, /au/ duration, and VAI. Each of these measures was higher in the older group when compared to the younger group.

**Effects of Speaking on Computer Task Performance**

A significant main effect was found for the text formatting task for the number of words highlighted correctly, the number of highlights missed, and the number of words underlined correctly. Comparison analysis revealed that for both Level 1 and Level 2 text formatting concurrently performed with speech, the number of words highlighted correctly significantly decreased compared to the tasks completed alone. It additionally revealed the number of correct
underlines significantly decreased in the Level 2 text formatting with speech task compared to the Level 2 text formatting task alone.

Testing revealed a significant main effect for the number of words sorted correctly in the data entry task. Correctly sorted words significantly decreased during the data entry with speech task compared to the data entry task alone. There was a significant effect of age on the number of correctly highlighted words and the number of correctly sorted words. There was a significantly lower number of correctly highlighted words during the text formatting tasks and correctly sorted words during the data entry task completed by the older age group when compared to the younger age group.

**Discussion**

The purpose of this study was to analyze the effects of divided attention on acoustic measures of speech production during the simultaneous completion of speech and computer tasks. We also examined the differences between younger and older adults’ performance in both speech and computer tasks. There were several significant changes in acoustic measures and in computer task performance, and there were also differences between age groups. For acoustic variables, there was a significant decrease for /aɪ/ F1 rate, /aɪ/ F2 rate, /aɪ/ F2 change, /aʊ/ F1 rate, /aʊ/ F2 rate, VSA, and VAI for several divided attention task conditions when compared to speech only tasks. There was a significant increase in /aɪ/ and /aʊ/ duration during divided attention speech tasks compared to speech alone.

**Findings in Relation to Previous Research**

The results of this study revealed that the extent of articulation significantly decreased when simultaneously completing a computer task as reflected in VSA, VAI, and diphthong rate and extent of change. These findings are consistent with previous kinematic research studies
which reported that participants used more restricted movements and decreased articulation during divided attention tasks (Bailey & Dromey, 2015; Dromey & Bates, 2005; Dromey & Shim, 2008). These studies used kinematic measures to analyze extent of articulation; however, the results are comparable to those of the current study in light of the general parallels between kinematic and acoustic metrics. These methods of analysis are both valid techniques to measure changes in articulation (Caverlé & Vogel, 2020).

The current study revealed a significant decrease in performance for both text formatting and data entry computer tasks during simultaneous speech production. These findings are consistent with previous research which found that performance on linguistic based computer tasks decreased while concurrently performing a speaking task (Bailey & Dromey, 2015; Dromey & Bates, 2005). While these previous studies also analyzed the effects of speaking on visuospatial and cognitive tasks and found no statistically significant changes, the current study primarily focused on various linguistically based computer tasks.

The present study additionally found that diphthong transition extent, diphthong duration, and VAI for several conditions was higher in the older adult age group when compared to younger adults. The longer diphthong duration is consistent with previous findings which revealed utterance duration in connected speech was significantly higher in older adults compared to the younger adult age group (Bailey & Dromey, 2015). There was no statistically significant difference in diphthong transition rate, contrasting with previous findings which revealed the speaking rate of older adults was significantly lower in dual-task conditions compared to younger adults (Kemper et al., 2005). Additionally, the present study found a significantly higher VAI for older participants, suggesting the older adults articulated more expansively than the younger adult group. These findings differ from previous research which
reported that older adults’ articulatory patterns were affected more by divided attention compared to younger adults (MacPherson, 2019).

**Effects of Computer Tasks on Acoustic Measures**

The study revealed a statistically significant decrease in VSA and VAI for all dual-task conditions compared to speech only conditions. VSA and VAI are subtle acoustic measures that are reflective of articulatory changes in speech. These objective measures can reveal differences between conditions that may not have been perceptible to listeners. VSA is calculated as the area enclosed by the four corner vowels: /a/, /i/, /æ/, and /u/. It indirectly reflects size of articulatory movements, in that more centralized vowels result in a smaller VSA (Whitfield et al., 2018). VAI likewise reflects the extent of the articulatory movements during the production of these vowels. It has been shown to be less sensitive to inter-speaker differences and better than VSA at detecting changes in articulation across speaking conditions (Roy et al., 2009). Therefore, a significant decrease in these granular measures of articulation indicates that the speaker is using smaller articulatory movements when challenged with divided attention tasks (Dromey et al., 2008). These articulatory changes are likely due to some degree of attentional overload during dual-task conditions. While the individual may continue to speak while completing a competing task, their speech mechanism provides less exaggerated articulatory movements. These findings suggest that typical speakers under-articulate in situations that require dividing their attention, especially while completing linguistically based tasks. Examples of these situations include speaking and sending a text message, reading a message while talking on the phone, or reading notes while public speaking.

The analysis revealed many statistically significant changes in the diphthong measures, reflecting overall changes in articulation. The /æ/ F2 transition extent significantly decreased
during the Level 1 text formatting task during speech compared to speech alone. This indicates that the extent to which a speaker’s tongue advanced in the mouth from beginning to the end of the diphthong decreased in that divided attention task. Additionally, the rate of F1 and F2 for both /au/ and /aʊ/ diphthongs significantly decreased in all dual-task conditions. This suggests that the speed of lingual movement during the diphthong transition for both tongue height and advancement decreased in each dual-task condition group compared to speech alone. Both /au/ and /aʊ/ duration increased significantly for speech during completion of the computer tasks, suggesting a decreased articulation rate in this condition. Taken together, these measurements reflect a slower rate, with less exaggerated movements in the production of these diphthongs. One possible explanation for the increase in diphthong duration may lie in the syntactical position of the word containing the diphthong. In the phrase repetition, “The thief hid his cash out of sight. They shout when the shot goes in the hoop.” The word “sight” is positioned at the end of the sentence. Speakers may have extended the production of the final word in the sentence when challenged with an increased cognitive load to provide additional time to generate the next phrase. The statistically significant decrease in diphthong rate and transition extent suggests the speakers used reduced articulatory gestures during the dual-task conditions. This is likely due to cognitive overload from the competing non-speaking task.

**Effects of Speaking on Computer Task Performance**

A significant effect was found for both the text formatting and the data entry computer tasks during the dual-task condition. The number of correctly highlighted and underlined words significantly decreased in the divided attention tasks when compared to the tasks completed alone. A possible explanation for decreased performance in these tasks is the linguistic nature of the text formatting task. This task required visually scanning a reading passage and identifying
“the” and “a” to highlight and underline. As this task relies on similar language centers to speech production, the functional distance hypothesis (Kinsbourne & Hicks, 1978) may be a plausible explanation for the interference between speech and the text formatting computer task.

The data also revealed a significant decrease in the number of correctly sorted words during the data entry task with speech compared to the task completed alone. This task required scanning, identifying, and copying words into semantically correct categories. The significant decrease in correctly sorted words during the data entry task suggests decreased performance overall on the task when completed in a dual-task condition. While both computer tasks involve language processing and cognitive effort, the data entry task also relied on generation of language. The extra step of recalling semantically relevant words and spelling them correctly in their corresponding categories may have caused more cognitive fatigue. Therefore, this task may have been more challenging than the text formatting task.

Effects of Age on Speaking and Computer Tasks

The results revealed /aɪ/ F2 change, /aɪ/ duration, /aʊ/ F2 change, /aʊ/ duration, and VAI to be statistically higher in the older adults compared to the younger adult age group. These findings suggest that the older participant group had a larger and slower transitions during the diphthong for both /aɪ/ and /aʊ/. Additionally, the older adult group reflected a statistically higher VAI suggesting the older adults articulated more expansively during production of corner vowels compared to the younger adult group. These results suggest older adults overall increased length of word productions and articulation compared to younger adults. Previous research has suggested older adults have more difficulty with divided attention tasks and cognitive load than younger adults (Fan et al., 2018; Tremblay & Ross, 2007). This may provide a possible explanation for the increase in duration of diphthong productions. This may be a compensatory
strategy to produce accurate speech when challenged with a difficult cognitive task (Kemper et al., 2005). It is also possible the older adult age group prioritized the speaking task more than the competing computer tasks. A possible explanation for changes in older adults’ speech and computer task results may be older adults’ decreased ability to perform multiple tasks simultaneously and the cognitive decline that occurs with age. Difficulties with memory, decreased attention, reasoning, and problem solving that results from cognitive decline would make the divided attention tasks increasingly difficult for older adults. Another possible explanation is the older adult participant groups’ experience with computers. While the younger age group may be accustomed to everyday computer software programs, older adults may have less experience and ease in completing typical computer tasks.

**Limitations of the Present Study and Directions for Future Research**

One possible limitation of the current study is the unnatural and extensive repetition of two phrases in the speech stimuli. This type of speech production is not an accurate representation of natural speech patterns. However, repetitive speech stimuli were intentionally chosen for the present study in order to allow a systematic comparison of segmental articulatory acoustic measures across conditions. This type of analysis requires tight experimental control and multiple tokens. Another possible limitation of the study was the placement of the target word within the sentence. As target words were positioned at the end of the sentence, they frequently resulted in glottal fry and made formant analysis more difficult. For example, in the sentence “they shout when the shot goes in the hoop” the word “hoop” frequently resulted in glottal fry due to decreased breath support at the end of the target phrase. The phonological design of the second sentence was another possible limitation of the study. In the phrase “they shout when the shot goes in the hoop”, participants frequently switched replaced words
producing, “they shot when the shot…” requiring self-correction. However, due to the need to place each target vowel between voiceless consonants within a semantically plausible phrase, it may be difficult to avoid using a target word at the end of the sentence.

Another limitation of the present study was difficulty controlling participants rate of speech. The participants were each instructed to speak at a typical speaking rate during both the speech only and dual task conditions. However, speakers frequently spoke at an unnaturally fast rate. Future research could analyze participants’ rate of speech at the whole utterance level to complement the segmental data reported here. Additionally, the present study did not assess acoustic differences between the first production and final repetition of the speech stimuli in a single given task. Future research could assess whether speakers’ articulatory measures changed across multiple repetitions of the same speech stimuli over time.

The current study revealed that typical speakers demonstrated less expansive articulation when challenged with a divided attention task. Future studies could examine acoustic measures in speakers with speech and language disorders or cognitive decline. This could provide insights about the way clinicians should approach therapy with these individuals. Speech language pathologists could use these findings to support evidence-based, practice of naturalistic therapy that is generalizable to multiple communicative contexts. For example, treatment sessions could incorporate targeting speech centered goals while completing other tasks simultaneously to maintain progress in speech intervention during divided attention tasks.

Conclusions

The current study revealed statistically significant bidirectional interference between all computer tasks and speech. Older speakers showed different articulatory patterns from the younger adults. These findings suggest that when individuals are challenged with simultaneous
speech and computer tasks, performance in both tasks decreases. Situations involving speaking with divided attention occur every day. By better understanding the effects of divided attention on speech, speech-language pathologists can develop functional intervention that will generalize to the everyday lives of multi-tasking individuals.
References

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[https://doi.org/10.1016/j.jcomdis.2008.10.001](https://doi.org/10.1016/j.jcomdis.2008.10.001)


[https://doi.org/10.1016/j.jcomdis.2007.03.008](https://doi.org/10.1016/j.jcomdis.2007.03.008)


## Tables

### Table 1

Descriptive Statistics for the Acoustic Variables

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>/ɑː/ F1 C</td>
<td>M 262.9</td>
<td>279.9</td>
</tr>
<tr>
<td>SD</td>
<td>94.6</td>
<td>97.4</td>
</tr>
<tr>
<td>/ɑː/ F1 Rt</td>
<td>M 3.21</td>
<td>2.67</td>
</tr>
<tr>
<td>SD</td>
<td>1.22</td>
<td>1.06</td>
</tr>
<tr>
<td>/ɑː/ F2 C</td>
<td>M 595.7</td>
<td>639.6</td>
</tr>
<tr>
<td>SD</td>
<td>165.7</td>
<td>162.5</td>
</tr>
<tr>
<td>/ɑː/ F2 Rt</td>
<td>M 7.28</td>
<td>6.11</td>
</tr>
<tr>
<td>SD</td>
<td>2.06</td>
<td>1.79</td>
</tr>
<tr>
<td>/ɑː/ F2 C</td>
<td>M 395.7</td>
<td>397.2</td>
</tr>
<tr>
<td>SD</td>
<td>118.3</td>
<td>128.4</td>
</tr>
<tr>
<td>/ɑː/ F2 Rt</td>
<td>M 4.96</td>
<td>4.56</td>
</tr>
<tr>
<td>SD</td>
<td>1.54</td>
<td>1.60</td>
</tr>
<tr>
<td>/ɑː/ F2 C</td>
<td>M 83.7</td>
<td>89.3</td>
</tr>
<tr>
<td>SD</td>
<td>15.9</td>
<td>19.5</td>
</tr>
<tr>
<td>VSA</td>
<td>M 323705</td>
<td>295397</td>
</tr>
<tr>
<td>SD</td>
<td>128030</td>
<td>113532</td>
</tr>
<tr>
<td>VAI</td>
<td>M 1.69</td>
<td>1.66</td>
</tr>
<tr>
<td>SD</td>
<td>0.14</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Note. Sp Only = speech task alone; Sp W/ Txt 1 = speech with Level 1 text formatting; Sp W/ Txt 2 = speech with Level 2 text formatting; Sp W/ DE = speech with data entry; C = change; Rt = rate; M = mean; SD = standard deviation; VSA = vowel space area; VAI = vowel articulation index.
## Table 2

*Linear Mixed Model Main Effects and Bonferroni Corrected Comparisons for the Acoustic Measures*

<table>
<thead>
<tr>
<th>Main Effect</th>
<th>Num df</th>
<th>Den df</th>
<th>F</th>
<th>p</th>
<th>Pairwise Comparisons</th>
<th>Sp W/ Txt 1</th>
<th>Sp W/ Txt 2</th>
<th>Sp W/ DE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>df</td>
<td>p</td>
<td>df</td>
<td>p</td>
</tr>
<tr>
<td>/a/ F1 C</td>
<td>3</td>
<td>1105.550</td>
<td>0.736</td>
<td>.530</td>
<td>1105.140</td>
<td>.973</td>
<td>1105.550</td>
<td>1.000</td>
</tr>
<tr>
<td>/a/ F1 Rt</td>
<td>3</td>
<td>1104.415</td>
<td>52.450</td>
<td>&lt;.001</td>
<td>1104.085</td>
<td>&lt;.001</td>
<td>1104.451</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>/a/ F2 C</td>
<td>3</td>
<td>1104.511</td>
<td>5.887</td>
<td>&lt;.001</td>
<td>1103.812</td>
<td>&lt;.001</td>
<td>1104.584</td>
<td>.774</td>
</tr>
<tr>
<td>/a/ F2 Rt</td>
<td>3</td>
<td>1104.582</td>
<td>63.750</td>
<td>&lt;.001</td>
<td>1104.136</td>
<td>&lt;.001</td>
<td>1104.630</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>/a/ Dur</td>
<td>3</td>
<td>1105.294</td>
<td>142.105</td>
<td>&lt;.001</td>
<td>1105.038</td>
<td>&lt;.001</td>
<td>1105.294</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>/æ/ F1 C</td>
<td>3</td>
<td>1097.553</td>
<td>0.446</td>
<td>.720</td>
<td>1097.067</td>
<td>1.000</td>
<td>1097.552</td>
<td>1.000</td>
</tr>
<tr>
<td>/æ/ F1 Rt</td>
<td>3</td>
<td>1097.527</td>
<td>9.837</td>
<td>&lt;.001</td>
<td>1097.113</td>
<td>&lt;.001</td>
<td>1097.526</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>/æ/ F2 C</td>
<td>3</td>
<td>1097.726</td>
<td>1.329</td>
<td>.264</td>
<td>1097.142</td>
<td>1.000</td>
<td>1097.724</td>
<td>1.000</td>
</tr>
<tr>
<td>/æ/ F2 Rt</td>
<td>3</td>
<td>1097.555</td>
<td>23.359</td>
<td>&lt;.001</td>
<td>1097.145</td>
<td>&lt;.001</td>
<td>1097.554</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>/æ/ Dur</td>
<td>3</td>
<td>1097.087</td>
<td>39.658</td>
<td>&lt;.001</td>
<td>1096.803</td>
<td>&lt;.001</td>
<td>1097.087</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>VSA</td>
<td>3</td>
<td>1077.422</td>
<td>24.928</td>
<td>&lt;.001</td>
<td>1077.005</td>
<td>&lt;.001</td>
<td>1077.531</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>VAI</td>
<td>3</td>
<td>1077.530</td>
<td>24.418</td>
<td>&lt;.001</td>
<td>1077.069</td>
<td>&lt;.001</td>
<td>1077.651</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*Note.* Sp W/ Txt 1 = Level 1 text formatting with speech; Sp W/ Txt 2 = Level 2 Text Formatting with speech; Sp W/ DE = data entry task with speech; Num df = numerator degrees of freedom; Den df = denominator degrees of freedom; C = change; Rt = rate; Dur = duration; VSA = vowel space area; VAI = vowel articulation index.
### Table 3

**Linear Mixed Model Effects of Age for the Acoustic Measures**

<table>
<thead>
<tr>
<th></th>
<th>Num df</th>
<th>Den df</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>/aɪ/ F1 C</td>
<td>1</td>
<td>57.103</td>
<td>1.069</td>
<td>.305</td>
</tr>
<tr>
<td>/aɪ/ F1 Rt</td>
<td>1</td>
<td>57.055</td>
<td>.919</td>
<td>.342</td>
</tr>
<tr>
<td>/aɪ/ F2 C</td>
<td>1</td>
<td>56.745</td>
<td>15.234</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>/aɪ/ F2 Rt</td>
<td>1</td>
<td>57.095</td>
<td>.023</td>
<td>.880</td>
</tr>
<tr>
<td>/aʊ/ Dur</td>
<td>1</td>
<td>57.015</td>
<td>5.511</td>
<td>.022</td>
</tr>
<tr>
<td>/aʊ/ F1 C</td>
<td>1</td>
<td>57.001</td>
<td>1.870</td>
<td>.177</td>
</tr>
<tr>
<td>/aʊ/ F1 Rt</td>
<td>1</td>
<td>57.058</td>
<td>.047</td>
<td>.829</td>
</tr>
<tr>
<td>/aʊ/ F2 C</td>
<td>1</td>
<td>57.062</td>
<td>6.788</td>
<td>.012</td>
</tr>
<tr>
<td>/aʊ/ F2 Rt</td>
<td>1</td>
<td>57.091</td>
<td>.510</td>
<td>.478</td>
</tr>
<tr>
<td>/aʊ/ Dur</td>
<td>1</td>
<td>56.766</td>
<td>13.466</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>VSA</td>
<td>1</td>
<td>56.973</td>
<td>1.473</td>
<td>.230</td>
</tr>
<tr>
<td>VAI</td>
<td>1</td>
<td>57.034</td>
<td>4.080</td>
<td>.048</td>
</tr>
</tbody>
</table>

*Note*. Num df = numerator degrees of freedom; Den df = denominator degrees of freedom; C = change; Rt = rate; Dur = Duration; VSA = vowel space area; VAI = vowel articulation index.
Table 4

Descriptive Statistics for Text Formatting Computer Tasks

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th></th>
<th></th>
<th>Old</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1 Txt Only</td>
<td>L1 Txt W/ Sp</td>
<td>L2 Txt Only</td>
<td>L2 Txt W/ Sp</td>
<td>L1 Txt Only</td>
<td>L1 Txt W/ Sp</td>
</tr>
<tr>
<td># Correct HL</td>
<td></td>
<td></td>
<td>M   SD</td>
<td>M   SD</td>
<td>M   SD</td>
<td>M   SD</td>
</tr>
<tr>
<td># HL Missed</td>
<td></td>
<td></td>
<td>8   3</td>
<td>7   3</td>
<td>6   2</td>
<td>4   2</td>
</tr>
<tr>
<td># Incorrect HL</td>
<td></td>
<td></td>
<td>0   0</td>
<td>0   0</td>
<td>0   0</td>
<td>0   0</td>
</tr>
<tr>
<td># Correct UL</td>
<td></td>
<td></td>
<td>5   1</td>
<td>4   1</td>
<td>4   2</td>
<td>3   1</td>
</tr>
<tr>
<td># UL Missed</td>
<td></td>
<td></td>
<td>1   2</td>
<td>1   1</td>
<td>1   1</td>
<td>1   1</td>
</tr>
<tr>
<td># Incorrect UL</td>
<td></td>
<td></td>
<td>0   0</td>
<td>0   0</td>
<td>0   0</td>
<td>0   0</td>
</tr>
</tbody>
</table>

Note. L1 Txt Only = Level 1 text formatting task alone; L1 Txt W/ Sp = Level 1 text formatting task with speech; L2 Txt Only = Level 2 text formatting task alone; L2 Txt W/ Sp = Level 2 text formatting task with speech; M = mean, SD = standard deviation; #C HL = the number of words highlighted correctly; #HL Miss = the number of highlighted words that were missed; # Inc HL = the number of words highlighted incorrectly; # C UL = the number of words underlined correctly; # UL Miss = the number of underlined words that were missed; #Inc UL = the number of words that were underlined incorrectly.
Table 5

Linear Mixed Model Main Effects and Bonferroni Corrected Comparisons for the Text Formatting Computer Task

<table>
<thead>
<tr>
<th>Main Effect</th>
<th>Num df</th>
<th>Den df</th>
<th>F</th>
<th>p</th>
<th>L1 W/ Without Speech</th>
<th>L2 W/ Without Speech</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>177</td>
<td>43.456</td>
<td>&lt;.001</td>
<td>177</td>
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<tr>
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<tr>
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<td>1.010</td>
<td>.319</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td># Incorrect UL</td>
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<td>116</td>
<td>1.027</td>
<td>.313</td>
<td>116</td>
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</tr>
</tbody>
</table>

Note. L1 W/ Without Speech = Level 1 text formatting with and without speech; L2 W/ Without Speech = Level 2 Text Formatting with and without speech; Num df = numerator degrees of freedom; Den df = denominator degrees of freedom; # Correct HL = the number of words highlighted correctly; # HL Missed = the number of highlighted words that were missed; # Incorrect HL = the number of words highlighted incorrectly; # Correct UL = the number of words underlined correctly; # UL Missed = the number of underlined words that were missed; # Incorrect UL = the number of words that were underlined incorrect.
Table 6

Descriptive Statistics for Data Entry Computer Tasks

<table>
<thead>
<tr>
<th></th>
<th>Young DE Only</th>
<th>Young DE W/ Speech</th>
<th>Old DE Only</th>
<th>Old DE W/ Speech</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>SD</td>
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<td>SD</td>
</tr>
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<td># Words Sorted Correctly</td>
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<td>3</td>
<td>8</td>
<td>2</td>
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<tr>
<td># Words Sorted Incorrectly</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td># Words Spelled Incorrectly</td>
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<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. DE Only = data entry task alone; DE W/ Speech = data entry task with speech; M = mean; SD = standard deviation.
Table 7

*Linear Mixed Model Main Effects for the Data Entry Computer Task*

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<tr>
<th></th>
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<th>Den df</th>
<th>F</th>
<th>p</th>
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</thead>
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</tr>
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<td>1</td>
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<td>.577</td>
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</tbody>
</table>

*Note.* Num df = numerator degrees of freedom; Den df = denominator degrees of freedom.
Table 8

Linear Mixed Model Effects of Age for the Computer Task Performance

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<th>Den df</th>
<th>F</th>
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<td>116</td>
<td>.313</td>
<td>.577</td>
</tr>
</tbody>
</table>

*Note.* Num df = numerator degrees of freedom; Den df = denominator degrees of freedom; # Correct HL = the number of words highlighted correctly; # HL Missed = the number of highlighted words that were missed; # Incorrect HL = the number of words highlighted incorrectly; # Correct UL = the number of words underlined correctly; # UL Missed = the number of underlined words that were missed; # Incorrect UL = the number of words that were underlined incorrectly.
Figures

Figure 1

*Means and Standard Deviations of /au/ F2 Change Across the Experimental Conditions*

![Figure 1: Means and Standard Deviations of /au/ F2 Change Across the Experimental Conditions](image1)

Figure 2

*Means and Standard Deviations of /au/ F2 Rate Across the Experimental Conditions*

![Figure 2: Means and Standard Deviations of /au/ F2 Rate Across the Experimental Conditions](image2)
Figure 3

Means and Standard Deviations of /a/ Duration Across the Experimental Conditions

Figure 4

Means and Standard Deviations of VSA Across the Experimental Conditions
Figure 5

Means and Standard Deviations of VAI Across the Experimental Conditions
APPENDIX A

Annotated Bibliography


**Objective:** The purpose of this study was to research the effects of divided attention on speech motor performance while completing three different non-speech tasks (linguistic, cognitive, and manual motor) across multiple age groups. **Participants:** This study included 30 men and 30 women with no history of speech or language disorders with the exception of one participant reporting a previous articulation error treated in childhood. The design included three age groups: younger adults (20-28 years), middle-aged adults (40-50 years), and older adults (58-70 years) with 10 male and 10 female participants in each age group. All participants were native speakers of English. **Method:** Each participant was seated in a sound booth to attain high-quality audio recordings and were fitted with a lightweight head-mounted strain gauge system to measure the vertical movements of the participant’s lips and jaw. A microphone was attached to the headset 10cm from the participants mouth to record speech productions. Each participant completed four tasks: a speech task, a linguistic task, a cognitive task, and a manual motor task; they were given a 30 second practice trial before each task. Each task was completed first in isolation and then each non-speech task was completed concurrently with repetition of a targeted sentence. Speech segments were later analyzed for utterance duration (ms), STI (variability of speech movements across repetitions) of the lower lip, and dB SPL across all conditions. **Results:** The results of the study revealed a significant
effect of condition on many speech variables including longer duration, decreased LL displacement, and increase in SPL during divided attention tasks. The study demonstrated a significant increase in mean utterance duration and decrease in performance for all non-speech tasks within the older participant age group. Sex was not found to have a significant effect on any speech measures. *Authors’ Conclusion:* This study provides evidence that various types of tasks influence stability of speech movement when attention is divided. This discovery increases the understanding of changes that occur in motor control without pathology as well as the taxing effects of multitasking situations on patients outside of the controlled clinic environment. It also provided evidence towards the conclusion that older adults may be particularly challenged during divided attention tasks. *Relevance to Current Study:* This study provides evidence of significant effects of concurrent non-speech tasks on speech motor performance across different tasks and age groups. However, this study did not examine the effects of non-speech tasks on acoustic measures of speech performance. The current study can build upon this study’s findings by measuring the effect of non-speech tasks with variability in difficulty on speech acoustic measures across age groups.


*Relevance to the Current Study:* This article provided background information regarding the effects of advancing age on cognitive function, including data reflecting decrease in overall brain volume and gray matter. The current study will build upon this knowledge to analyze divided attention performance in older adults compared to younger adults.
Objective: The purpose of this study was to retrospectively analyze the effects of age on overall brain volumes across adulthood. Participants: The study included data on brain volumes and ages of 563 healthy adults ages 20-86 years (55% female participants).

Method: A FreeSurfer segmentation software was used to produce retrospective regional volumetric variables from 3D T1-weighted MRI scans of each participant. A regression model was then used to examine the linear and nonlinear correlations of whole-brain variable changes with increasing age. Authors’ Conclusion: The overall brain volumes declined significantly over the age range 20-86 years. The linear model with rising ages reflected a peak in brain volume in the fourth decade and a significant decrease after that point. Relevance to the Current Study: The current study will build upon this knowledge of brain volumes and aging to form researched-based hypotheses regarding the performance of older adults in dual-task conditions.


Objective: The purpose of the study was to investigate the stability, reliability, and sensitivity of three vowel space measurements: formant centralization ratio (FCR), vowel space area (VSA), and vowel articulation index (VAI). Participants: The study analyzed previously published data from healthy young adult native speakers of Australian
English. **Method:** Speech samples of the Grandfather Passage were recorded on a laptop. Target vowels were extracted and analyzed from the speech sample using PRAAT (Boersma & Weenink, 2023) for F1 and F2 values. Statistical analysis was then completed for reliability, stability, and sensitivity of each vowel space measurement. **Authors’ Conclusion:** Vowel space measurements do not always yield reliable outcomes in healthy speakers, varying from one production to the next, even when change is unexpected. **Relevance to the Current Study:** The current study will build upon this knowledge to increase reliability of the data by finding the F1 and F2 values of five repetitions of speech stimulus for each condition for each participant in the study.

https://doi.org/10.1044/1092-4388(2005/020)

**Objective:** The purpose of this study was to analyze the effects of concurrent linguistic, cognitive, and visuomotor tasks on speech motor performance in comparison to speech performance when speaking only. **Participants:** This study included 10 females (M = 22.4 years) and 10 males (M = 24.5 years) with no history of speech, language, or hearing disorders. **Method:** Participants were seated in a sound booth with a head-mounted microphone for optimal recording. The participants' lip and jaw movements were recorded using a strain gauge system. Participants completed a linguistic, cognitive, and visuomotor computer task, first in isolation and then simultaneously in a dual-task condition with the speaking task for a total of seven conditions. Lip and jaw movements were recorded for each task condition and analyzed for utterance duration, displacement, peak velocity, upper/lower lip correlation, spatiotemporal index (STI) for the lower lip-
plus-jaw, and sound pressure level (SPL). Each non-speech task was also analyzed, and task scores were computed. **Results:** A significant increase in utterance duration was found for the speech-plus-cognitive task condition and a decrease was found for the other dual-task conditions. Lower lip-plus-jaw displacement significantly decreased for the combined visuomotor task and STI significantly increased in the combined linguistic task when compared to the speech-only condition. The speakers were also found to have higher speech intensity when combining the speech and linguistic task than in the speech task alone. **Authors’ Conclusion:** This study analyzed the effects of divided attention interference on speech when completing other skilled activities. It was found that typically speaking adults change their performance when coordinating multiple activities simultaneously. **Relevance to Current Study:** This study found significant effects on participants' speech when performing other skilled activities at the same time providing evidence that divided attention while speaking has effects on a person’s speech. The current study will build upon this knowledge to discover the effects of divided attention on articulatory acoustic measures in a structured speech stimulus.


**Objective:** The purpose of this study was to analyze whether manual circumlaryngeal techniques to treat muscle tension dysphonia (MTD) are effective in improving articulatory performance reflected by acoustic correlates of articulatory change.

**Participants:** The study analyzed the voice samples of 157 patients with muscle tension...
dysphonia pre- and post-treatment. Each participant was diagnosed with MTD by a speech-language pathologist and an otolaryngologist through extensive perceptual and endoscopic evaluation. **Method:** Each speech sample was analyzed for the transition extent, transition duration, and transition slope for F1 and F2 in the diphthongs /au/ and /ei/. Reading sample duration, speaking time ratio, and listener ratings of voice quality were each collected. All values were compared across pre- and post-treatment conditions to analyze the effects of treatment. **Authors’ Conclusion:** The study found statistically significant changes in many acoustic variables, including an increase in F2 slope, fewer pauses, and an overall shorter sample duration following treatment in the MTD group, suggesting post-treatment improvements in articulation. **Relevance to the Current Study:** This study provided information regarding vowel space measures of acoustics and an evidence-based method of using them to analyze differences following treatment.


**Objective:** The purpose of this study was to examine the lingual kinematic and acoustic effects of bite blocks on vowels in a sentence context. **Participants:** This study included 10 male and 10 female adult native English speakers with no history of speech, language, or hearing disorders. **Method:** The corner vowels /u/, /a/, /i/, and /ae/ were segmented and analyzed from the sentence “The blue spot is on the black key again” before and after bite block insertion for each participant. Their lingual articulatory movements were also measured with a Wave electromagnetic articulograph from sensors attached to the back, middle, and front of the tongue. **Authors’ Conclusion:** The results revealed that both
vowel articulation index and vowel space area decreased significantly following bite block insertion. The kinematic vowel articulation index decreased for the back and middle of the tongue but not for the front. The authors suggested that acoustic and kinematic analysis paired together can more fully represent articulatory performance.

Relevance to the Current Study: The current study will use similar measures of acoustic analysis to assess the articulatory changes of the same corner vowels in a series of different dual-task conditions.


Objective: The purpose of this study was to examine the effects of various divided attention tasks on speech and language performance and whether tasks regulated by brain networks in closer anatomic proximity would have a higher interference than tasks controlled by spatially distant regions. Participants: The study included 10 men (M=22.8 years) and 10 women (M=21 years). All of the participants were right-handed native speakers of English with no history of speech, language, or hearing disorders. Each participant passed a hearing screening bilaterally. Method: Each participant was seated in a sound booth and attached to a head-mounted strain gauge system to measure lip and jaw movements. A microphone was attached to the strain gauge system to record vocal responses. Participants completed isolated and dual task conditions in a randomized order including speech motor, verbal fluency, and manual motor tasks. The motor task was completed with one trial per hand simultaneously with either the speech motor or verbal fluency task. The speech motor task included participants repeating a target phrase. The
verbal fluency task involved participants listing as many words as possible beginning with a given letter. The manual motor task included placing metal pegs and washers along a pegboard. Performance measures were analyzed for each task in isolation and dual-task conditions. Kinematic analyses were completed to obtain utterance duration, displacement, velocity, STI for the lower lip, and sound pressure level (SPL) for each speaking task. Results: The study found a significant decrease in the displacement of the lower lip as well as peak velocity in the left- and right-handed pegboard conditions. The STI significantly increased during the simultaneous left-handed pegboard task and SPL increased significantly in the concurrent pegboard task for both hands. A significant decrease of pegboard performance was found for both hands when performed concurrently with the verbal fluency task but not with the speech task. Authors’ Conclusion: The findings from the study provide limited evidence to support the functional distance hypothesis, suggesting, it may not be an adequate representation of dual task interference. The authors suggested that cognitive resources used to complete dual tasks may be more complex than what can be represented in a simple model. Relevance to Current Study: This study provides previous research of increased sensitivity measures as a means of reporting effects of divided attention during speech. The current study will build upon this evidence to measure another form of sensitive measures through acoustic analysis rather than lower lip displacement measures alongside various forms of divided attention tasks.


https://doi.org/10.1044/2018_JSLHR-S-MSC18-0146
**Objective:** The purpose of this study was to analyze how divided attention while speaking and simulated driving affects acoustic measures of connected speech and driving performance. **Participants:** This study included 30 men and 30 women evenly divided into three age groups: young adults (20-30 years), middle aged adults (40-50 years), and older adults (60-71 years). All participants were native English speakers with no history of speech, language, or hearing disorders. **Method:** Each participant was seated in a sound booth and wore a microphone headset to record their verbal responses. The participants used a steering wheel and gas/brake pedal on a lab computer to simulate driving on a virtual road. The speech and driving tasks were each completed in isolation and simultaneously in a dual-task condition. Acoustic measures of connected speech and quantifiable driving performance data were computed to determine performance levels of each task. **Results:** The dual task condition had significant effects on speech performance including lower speaking time ratios and increased average intensity of speech when compared to the isolated condition. The dual task condition also resulted in increased speed and number of steering wheel turns for driving performance. **Authors’ Conclusion:** The findings from the study may have clinical implications for the treatment of patients with communication disorders. Divided attention during speech is more common than a controlled optimal environment. Therefore, patients may more efficiently generalize skills if treatment is adjusted to simulate everyday communication. **Relevance to Current Study:** This study followed procedures similar to the current study, providing background knowledge for method used. However, the current study will analyze computer-based tasks and segmental acoustic measures.

**Objective:** The purpose of this study was to use diffusion tensor imaging (DTI) tractography to analyze the relationship between age, changes in white matter integrity, and cognitive function. **Participants:** The study included healthy 16 young adults (20-28 years) and 18 healthy older adults (60-75 years) with no history of neurological or psychiatric disorders. **Method:** Each participant underwent DTI scanning and a standardized battery of neuropsychological measures including the Mini-Mental State Examination (MMSE) and the Montreal Cognitive Assessment (MOCA). A statistical analysis was completed to analyze associated relationships. **Authors’ Conclusion:** The study provides evidence for an association between changes in white matter integrity and age-related cognitive decline. Therefore, advanced age is associated with poorer performance on neuropsychological tests. **Relevance to the Current Study:** The current study will build upon this knowledge to analyze the impact of cognitive load on divided attention on performance in multiple tasks in younger and older adults.


**Relevance to the Current Study:** This book provided background information regarding the effects of aging on speech breathing performance. While the current study will analyze the effects of age on articulation performance, this information provides basic knowledge about the speech production of older adults overall.

*Relevance to the Current Study:* This journal article provided additional evidence for the effects of aging on speech breathing performance. The current study will build upon this knowledge to analyze the effects of age on articulation performance.


*Relevance to the Current Study:* This study provided relevant information regarding single, undifferentiated resource theories of attention. This information provided valuable context and background information for the current study when analyzing performance in dual tasks that may lead to interference.


*Objective:* The purpose of this study was to analyze the differences in fluency, grammatical complexity and informational content between young and older adults' speech production while concurrently performing 3 different motor tasks. *Method:* The study originally screened 26 young adults (18-28 years) and 37 older adults (70-80 years) for hearing acuity. Participants who demonstrated significant hearing loss were excluded from participation in the study, resulting in a final 24 young adults (M = 21.5) and 24 older adults (M = 74.8) to participate in the study. Participants completed five tasks: talking alone, walking alone, walking while talking, walking and talking while carrying a 10 lb. bag of groceries, and walking and talking while climbing steps. These tasks were administered in a random order. Each participant was digitally video- and audio-recorded
during each of the tasks. The recordings were analyzed and coded according to behaviors. Each audio sample was analyzed for fluency, grammatical complexity, and informational content. Results: When presented with the dual-task conditions, young adults adopted a restricted speech register composed of shorter, less complex sentences in comparison to their normal speech register. Older adults, who were already using a restricted speech register, responded to the dual-task condition by both walking and speaking more slowly than presented in isolated speech and motor tasks. Additionally, older adults became more disfluent and used more fillers than in the speech only condition. Authors’ Conclusion: The grammatical complexity and propositional content of older adults’ speech appears to be buffered from dual task demands due to their compensatory reactions of reduced walking and speaking rates, alternating walking and talking, and using more fillers and shorter sentences. However, older adults demonstrated their ability to utilize cognitive reserve capacity to maintain complexity and content of their speech production. Relevance to Current Study: This study presented valuable information regarding the effects of dual-task conditions on older adults in comparison to younger adults. However, this study did not analyze isolated speech variables to determine the motor speech differences between the age groups. The current study will analyze the objective differences of the two age groups' speech production, without the influence of compensatory reactions, speaking rate, or grammatical structure.


https://doi.org/10.1080/13825585.2010.527317
Objective: The purpose of this study was to analyze the effects of speech planning, production, and output on visuo-motor tracking performance. The study also investigated personal-level predictors and utterance-level predictors of dual task performance.

Participants: The study included 40 young adult (18-34 years) and 40 older adult (65-85 years) participants. The two groups of participants reflected a similar number of years of formal education completed. Each participant was tested on verbal ability, working memory, inhibition, and processing speed. Method: Each participant completed a rotor tracking task in which they selected a moving target on a computer screen using a mouse-controlled pointer. Following practice and baseline tasks, the participants completed a dual task condition in which they tracked the moving target while responding orally to a verbal prompt. The verbal responses were coded and pauses between utterances were determined through the ROSS utility. Results: The study determined that the mean tracking error (TE) increased and the mean time on target (TOT) decreased when the next utterance was propositionally dense. Tracking performance also declined during the pauses before utterances, the production of utterances, and after the utterances were completed. Authors’ Conclusion: Speakers who are planning to include dense information in their next utterance have increased difficulty with rotor tracking regardless of age or cognitive ability. This evidence supports previous findings that speaking while simultaneously performing another task has consequences of both concurrent activities for young and older adults. Specifically, speech slows down, becomes shorter, and less grammatically and propositionally dense. Relevance to Current Study: This study provides knowledge of the effects of divided attention during speaking tasks on both an individual’s speech production as well as the non-speech task. The current study will
build upon this knowledge to analyze the effects at a more controlled and structured level.


**Objective:** The purpose of this study was to analyze the effects of dual task costs on language production of younger and older adults, specifically whether a digital pursuit rotor task performed simultaneously with a language sample will result in dual task costs to tracking, fluency, and grammatical complexity across both age groups. **Participants:** 40 young adults (18-34 years) and 40 older adults (65-85 years) were included in the study. Two additional young adults and three additional older adults were tested but removed from the data due to technical problems during testing. Participants did not differ significantly in length of formal education and completed a cognitive battery prior to admission to the study. **Method:** Each participant completed a pursuit-rotor tracking task via a 4 in by 6 in touchpad or a trackball mouse to control the cursor and track the target, which was displayed on a 15 in flat-screen. The task required participants to use their cursor to follow a moving target at various speeds for various durations. After completion of the tracking task in isolation, each participant completed the rotor tracking task simultaneously with a language sample of reading and responding verbally to a prompt. Dual task costs (DTCs) were calculated to assess divided attention impacts on tracking performance and language production. **Results:** The study found a significant decrease in time on target and increase in tracking error while talking in both the younger adult and older adult age groups. The younger adult age group was found to use longer
sentences with a more rapid speaking rate than the older adult age group. The older adults were found to use more complex sentences with fewer filler words and higher propositional density. **Authors’ Conclusion:*** The study found similar effects of tracking performance on concurrent language performance in younger and older adult groups. These findings suggest that individual differences in working memory and processing speed affect performance on dual task conditions. Additionally, this study supports previous findings that older adults adopt a simplified register as a conservative approach to dual task demands. **Relevance to Current Study:** This study provides valuable evidence of dual-task costs on language production across younger and older adults. However, this study focuses on measurements of language production. The current study will build upon this knowledge to analyze dual-task costs on articulatory acoustic measures of speech production.

[https://doi.org/10.4324/9781003310228](https://doi.org/10.4324/9781003310228)

**Relevance to the Current Study:** This study provided information regarding the functional distance hypothesis which was later studied by others. The current study will consider this theory of attentional resources when discussing the results of participants’ performance.

[https://doi.org/10.1044/2018_JSLHR-S-17-0222](https://doi.org/10.1044/2018_JSLHR-S-17-0222)
Objective: The purpose of this study was to analyze the impact of a simultaneously completed task on the speech motor performance of older and younger adults.

Participants: The study included 12 younger adults (22-32 years) and 12 older adults (68-78 years). All participants were native speakers of English with no history of speech, language, or hearing disorders. All participants were also right-handed. Method: Participants were seated in front of a computer monitor from which single sentence stimuli with colors embedded. The sentences incorporated a STROOP test format of altering the font color of the color words. Two forms were included: a congruent condition (same font color and word) and an incongruent condition (different font color and word). Articulatory kinematic data were collected and analyzed across the sentence productions to determine LAVAR index, movement duration, and percentage of accurate sentence productions. Results: The study found that for both older and younger adults, the LAVAR index was significantly greater in the incongruent condition than the congruent condition. Additionally, the LAVAR index of older adults was significantly greater than that of the younger adults. The study found no significant difference in the percentage of accurate sentence productions between younger and older adults in the congruent Stroop condition. However, the accuracy of sentence productions was significantly lower for the older adults than younger adults in the incongruent Stroop condition. Authors’ Conclusion: The findings from the study suggest that increased cognitive load negatively impacted the speech motor performance of both younger and older adults. These findings are consistent with models of speech production in which external factors affect speech motor performance. Relevance to the Current Study: This study analyzed the effects of cognitive load on speech motor performance through an
isolated task requiring sustained attention. The current study will build upon this knowledge to determine the speech motor effects of dual-task conditions requiring divided attention, a different form of cognitive load.


*Relevance to Current Study:* This chapter provided valuable information pertaining to attention in divided attention dual-task conditions. It built upon this knowledge to address factors to consider while developing tasks for a dual-task condition study. The current study will build upon this knowledge when developing tasks for analysis.


*Relevance to Current Study:* The article provided background knowledge on different types and models of attention. This knowledge will create a deeper understanding of divided attention and attentional resource theories for preparing and analyzing divided attention tasks in the current study.


*Relevance to the Current Study:* This article provided knowledge of the single-bottleneck theory and resource theories of attention in dual-task conditions. This knowledge will be beneficial in the analysis and interpretation of the results of the current study.

**Objective:** The purpose of this study was to analyze the effects of divided attention on the occurrence of filled pauses and repetitions in the speech production of typical speakers. This was conducted to better understand the association between attention and disfluency.

**Participants:** The study included 18 participants (11 women and 7 men) between 19 and 24 years old. The participants were native speakers of Dutch with no history of speech, language, or hearing disorders. **Method:** The participants completed a story picture description task and tactile-perception task each twice in isolation and once simultaneously in a dual-task condition. The tactile-perception task consisted of blindly exploring sand-paper figures. For each figure, the participants identified the tactile object from four multiple-choice options including the figure and 3 distractors. All responses were recorded, transcribed, and scored for presence of filled pauses and repetitions (sound, word, and phrase). **Results:** The study found that more filled pauses and repetitions were present in the divided attention condition than in the speech-only condition for the majority of the participants. Additionally, the presence of the speech production task also affected performance on the tactile perception task. **Authors’ Conclusion:** The findings from this study do not support previous hypotheses that disfluencies are attentionally governed reactions to speech planning problems. If disfluencies were truly governed by attentional processes, the number of filled pauses and repetitions should decrease in a situation where there is less room for attentional control. **Relevance to Current Study:** This study provides evidence supporting the hypothesis that
divided attention affects speech performance, specifically the fluency of speech production. The current study will build upon this knowledge to analyze the effects of divided attention on articulatory performance.


**Objective:** The purpose of this study was to analyze the effects of muscle tension dysphonia (MTD) on vowel articulation via acoustic measures of vowel productions in pre- and post-treatment measures. **Participants:** This study analyzed the vowel productions from the original participants in (Dromey et al., 2008) study. **Method:** From the digital recordings of The Rainbow Passage pre- and post-treatment, acoustic measures were collected from the corner vowels /i/, /æ/, /a/, and /u/, including vowel space area (VSA), vowel articulation index (VAI), and perceptual ratings. **Authors’ Conclusion:** The findings were consistent with the Dromey et al. (2008) study, in that there were statistically significant increases in VSA and VAI following MTD treatment. **Relevance to the Current Study:** The current study will use similar measures to analyze the difference in VSA and VAI of participants in speech only and dual-task conditions.


**Relevance to the Current Study:** This journal article provided valuable background information about the effects of age on the brain, specifically regarding physiological
changes and cognitive decline. The current study will consider these findings in analysis of performance results in older adults compared to the younger adult participant group.


**Objective:** The purpose of this study was to analyze the effects of speech intensity on acoustic and kinematic vowel space measures. **Participants:** The study included 20 young adults (10 men and 10 women) who were native speakers of American English and had no history of speech, language, or hearing disorders. **Method:** Each participant was fitted with sensor coils on the tongue, lips, and lower incisors. Each participant recited the phrases, “It’s time to shop for two new suits” and “A good AC should keep your car cool” containing three corner vowels in different phonemic contexts. The audio recordings were segmented and analyzed for F1 and F2 measures for VAI and VSA, and the kinematic equivalents of VAI and VSA were computed in MATLAB. All the collected data were analyzed across vocal intensity levels. **Authors’ Conclusion:** The study found a statistically significant relationship between kinematic and acoustic vowel space metrics. Additionally, loudness-related changes did not reflect statistically significant changes on VSA and VAI measurements. **Relevance to the Current Study:** The information from this study ensures the evidence base for the measurement methods used in the current study. The data demonstrates that acoustic measures are a good representation of articulatory performance.

Objective: The purpose of this study was to analyze the extent to which divided attention through a simultaneous manual task will affect the connected speech of individuals with and without Parkinson’s Disease. Participants: This study included 12 participants with Parkinson’s Disease (nine males, three females) and 11 neurologically healthy controls (two males, nine females). The mean age of the participants was 67 years. All participants were right-handed, and no controls had any history of speech, language, or hearing disorders. Method: Participants completed two speaking tasks: a paragraph reading and an extemporaneous speech task in which they were prompted to talk about a particular topic for several minutes. Participants completed an oscillatory motor task of a counter-clockwise circle-drawing task using the dominant hand. Each task was completed first in isolation, then the speaking tasks were each performed concurrently with the manual task. Speech samples were collected using a head-mounted microphone and analyzed for articulatory-acoustic vowel space, speech rate measures, speech intensity, and F0 variability. Results: Statistically significant differences between controls and speakers with Parkinson’s Disease (PD) were found for some of the acoustic measures. Speakers with PD also demonstrated significantly longer pause durations than the controls in the extemporaneous task. No significant differences were found for speech intensity between the two groups. The study did not find significant acoustic differences with the dual-task conditions between the two groups. Authors’ Conclusion: The findings from the study suggest differences between speakers with PD and typical speakers may be more prosodic than articulatory in nature. The authors suggest future research.
regarding linguistic and grammatical measures in single and dual-task conditions should be completed. *Relevance to the Current Study:* This study analyzes speech acoustic measures to determine the effects of dual-task conditions on speech of controls and speakers with PD. The current study will use similar acoustic measures to this study to determine the effects with various dual-task conditions across age groups.


*Relevance to the Current Study:* This book chapter provides background information regarding resource theories of attention. Specifically, the author introduced attention as a multi-dimensional resource that relies on separate pools of resources for different types of cognitive processing.


*Relevance to the Current Study:* This study included evidence regarding the effects of aging, both generally and in speech. This information contributed to the current study by providing a rationale for evaluating speech and cognitive performance differences between younger and older adults.
Appendix B

Consent Form

Consent to be a Research Subject

Title of the Research Study: Effects of Concurrent Computer Use on Speech Acoustics and Physiologic Arousal  
Principal Investigator: Christopher Dromey, PhD  
IRB ID#:

Introduction
This research study is being conducted by Professor Christopher Dromey, assisted by Tiana Bateman, Chanelle Thomas, and Paige Snow from the Department of Communication Disorders at Brigham Young University, to determine how speaking while completing another task can influence both the way a person speaks and how well they complete the other task. You were invited to participate because you are a native speaker of American English and have no history of speech, language, or hearing disorders.

Procedures
If you agree to participate in this research study, the following will occur:
• you will sit in a sound-treated booth in room 106 of the John Taylor Building for a recording session
• you will complete a brief hearing screening
• you will wear a headset microphone to record your speech
• you will have sensors attached to your foot to measure skin responses associated with stress
• you will be handed 3 small electrodes and asked to attach them to yourself near your collar bone and stomach
• you will read aloud sentences that will be presented on a computer screen in front of you
• you will be asked to describe how to complete a task, such as making a sandwich or carry on a conversation with the experimenter
• you will complete some computer-based tasks, such as formatting text, responding to yes/no questions about sentence accuracy or simple math problems
• sometimes you will be speaking while you do nothing else; sometimes you will be speaking at the same time you are working on a computer task
• total time commitment will be 60 minutes in one recording session

Risks/Discomforts
No risks are associated with the study beyond that experienced in everyday life. You might feel fatigued during the session, especially while multitasking. You may take a break at any time during the study to rest. If the audio recordings were to be exposed to a breach of privacy, they will not have your name associated with them and will only involve everyday topics of conversation. See the Confidentiality section below.
Benefits
There will be no direct benefits to you as a participant. However, we anticipate that the findings from this study will benefit the field of speech pathology by helping us design better treatments for people with speech problems.

Confidentiality
The research data will be kept on password protected computer and only the researchers will have access to the data. Before we analyze the recordings, all identifying information will be removed so that your name will not be linked to the recordings. Only summary data from groups of participants will be reported in publications and presentations. After the study the de-identified data will be kept on a password-protected computer in the researcher’s office for possible future analysis with new techniques.

Compensation
You will receive $10 for your participation, whether you finish the recording or not; compensation will not be prorated.

Participation
Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without jeopardy to your class status, grade, or standing with the university.

Questions about the Research
If you have questions regarding this study, you may contact Christopher Dromey at 133 TLRB, 801-422-6461, dromey@byu.edu for further information.

Questions about Your Rights as Research Participants
If you have questions regarding your rights as a research participant contact IRB Administrator at (801) 422-1461; A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu.

Statement of Consent
I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Name (Printed): __________________________ Signature __________________________ Date: __________
Memorandum

To: Christopher Drome
Department: BYU - EDUC - Communications Disorders
From: Sandee Aina, MPA, HRPP Associate Director
Wayne Larsen, MAcc, IRB Administrator
Bob Ridge, Ph.D., IRB Chair
Date: December 09, 2021
IRB#: IRB2021-362
Title: Effects of Concurrent Computer Use on Speech Acoustics and Physiologic Arousal

Brigham Young University's IRB has approved the research study referenced in the subject heading as expedited level, categories 4 and 6. The approval period is from 12/09/2021 to 12/08/2022. Please reference your assigned IRB identification number in any correspondence with the IRB. Continued approval is conditional upon your compliance with the following requirements:

1. A copy of the approved informed consent statement and associated recruiting documents (if applicable) can be accessed in iRIS. No other consent statement should be used. Each research subject must be provided with a copy or a way to access the consent statement.
2. Any modifications to the approved protocol must be submitted, reviewed, and approved by the IRB before modifications are incorporated in the study.
3. All recruiting tools must be submitted and approved by the IRB prior to use.
4. In addition, serious adverse events must be reported to the IRB immediately, with a written report by the PI within 24 hours of the PI's becoming aware of the event. Serious adverse events are (1) death of a research participant; or (2) serious injury to a research participant.
5. All other non-serious unanticipated problems should be reported to the IRB within 2 weeks of the first awareness of the problem by the PI. Prompt reporting is important, as unanticipated problems often require some modification of study procedures, protocols, and/or informed consent processes. Such modifications require the review and approval of the IRB.
6. A few months before the expiration date, you will receive a prompt from iRIS to renew this protocol. There will be two reminders. Please complete the form in a timely manner to ensure that there is no lapse in the study approval. Please refer to the IRB website for more information.

Instructions to access approved documents, submit modifications, report complaints, and adverse events can be found on the IRB website under iRIS guidance: https://irb.byu.edu/iris-training-resources.