2018-03-01

Effects of Divided Attention on Speech in Parkinson's Disease

Melissa Inkley
Brigham Young University

Effects of Divided Attention on Speech in Parkinson's Disease

Melissa Inkley

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

Master of Science

Christopher Dromey, Chair
Shawn Nissen
Kathryn Cabbage

Department of Communication Disorders

Brigham Young University

ABSTRACT

Effects of Divided Attention on Speech in Parkinson's Disease

Melissa Inkley
Department of Communication Disorders, BYU
Master of Science

The effects of divided attention on speech in Parkinson's disease (PD) have been studied for a variety of tasks in recent years. Much of the previous research studied gait patterns while participants concurrently performed another task. There have been few studies regarding the effects of divided attention on speech in individuals with PD. The ability to communicate effectively relies in part on an appropriate rate of speech, vocal intensity, and fundamental frequency control. This study included 27 participants: 8 with PD, 12 neurologically healthy older (HO) adults, and 7 healthy younger (HY) adults. Each participant was given a list of topics to speak about during the experiment. They produced monologues under three conditions: standing, walking on a treadmill, and walking over obstacles on a treadmill. Each monologue was recorded and trimmed of pauses between topics, experimenter speech, and nonspeech behaviors before analysis. Speech rate, speaking versus pausing time, overall intensity, and intensity and fundamental frequency (F_0) variability were analyzed. Median, mean, maximum, and minimum F_0 increased as the gait task increased in difficulty. Mean and standard deviation of intensity also increased with gait demands. All groups had increased intensity variability when walking compared to standing. Speaking versus pausing time did not differ significantly as a function of the walking task and the results varied across the groups; the same was true for speech rate. These findings reflect changes in performance during divided attention tasks, with a greater effect on HO adults and individuals with PD than their younger counterparts.

Keywords: Parkinson's disease, divided attention, aging speech

ACKNOWLEDGMENTS

I would like to thank my committee for their support throughout the process of writing this thesis. I am deeply grateful to Dr. Christopher Dromey who provided me with countless hours of feedback and mentoring. His enthusiasm and support were a driving force in the completion of this project. I would like to express gratitude to Dr. Shawn Nissen and Dr. Katy Cabbage who contributed valuable feedback and guidance during the planning and revision stages of writing.

I would like to thank my parents for their constant motivation, patience, and examples of perseverance as I moved forward in pursuit of my dreams. I would not have reached this point in my educational and personal development if not for their loving encouragement. I am grateful to my sisters for being pillars of strength and confidence from beginning to end. My family added perspective during difficult days, happiness to the journey, and shed light at the end of the tunnel.

I would also like to acknowledge the support and friendship of my cohort. They are a remarkable group of individuals who have made traveling through the trenches of graduate school not only bearable, but enjoyable. I am beyond grateful to be able to call them colleagues and friends. This has been a rich and rewarding educational experience for which I will be forever grateful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DESCRIPTION OF THESIS STRUCTURE

This thesis, *Effects of Divided Attention on Speech in Parkinson's Disease*, is written in a hybrid format, with a combination of traditional university thesis requirements and recent peer-reviewed communication disorders journal articles. The preliminary pages of this thesis reflect requirements for submission to the university. An annotated bibliography is included in Appendix A. Information regarding the research consent form is included in Appendix B. Narrative triggers used during data collection are included in Appendix C.

Introduction

All individuals, both young and old, tend to be most successful at completing a task when it has their full and undivided attention. However, we live in a world where it has become increasingly difficult for individuals to perform all tasks singularly and without distraction. Our day-to-day lives have become dependent on multitasking, or dividing our attention among tasks, in order to be productive. Due to the many resources at our fingertips we end up executing two or more tasks at one time, such as watching television while eating dinner, talking on the phone while driving, or responding to an email during an important work meeting. Dividing our attention between two or more tasks lessens the cognitive focus we can give to each, thus decreasing the effectiveness of the execution of one or all of the tasks. This decline in performance is known as *interference*. Additionally, we know the natural aging process has an effect on the ability of older individuals to execute multiple tasks with the same accuracy or precision as their younger counterparts (Kemper, Schmalzried, Hoffman, & Herman, 2010). Beyond this, and further complicating the process, individuals who approach multiple tasks with an already impaired neurological state such as Parkinson's disease may have even greater difficultly dividing their attention between tasks, thus compromising other tasks, such as speaking (LaPointe, Stierwalt, & Maitland, 2010).

Speech in Parkinson's Disease

Parkinson's disease (PD) is a progressive neurodegenerative disease affecting dopamine production in the brain. Parkinson's disease is usually diagnosed later in life with the disease and symptoms progressing gradually over time. Dopamine is produced mainly within the substantia nigra and contributes to the production of smooth and coordinated movements. When dopamine producing cells in the substantia nigra are damaged, the basal ganglia over-inhibit the cortical drive to the body, resulting in the motor symptoms seen in PD. These include tremor, slowness of movement (called bradykinesia), stiff muscles, limited facial expressions, decreased ability to perform automatic movements, an impairment in posture and balance, along with changes in writing and speech.

Dysarthria, a disorder of verbal communication resulting from nervous system damage affecting the muscular movements required for speech, occurs in approximately 90% of individuals with PD (Tjaden, 2008). Dysarthria affects multiple subsystems of expressive communication including articulation, respiration, phonation, and resonance, causing decreased speech intelligibility. The type of dysarthria most frequently co-occurring with PD is *hypokinetic* dysarthria, so named because the individual has slowness, weakness, and a reduced range of motion affecting the systems required for speech. Placement of the articulators may appear to be accurate but the range of motion is reduced causing decreased speech movements. Speech characteristics of hypokinetic dysarthria may include an increased rate of speech, decreased loudness (hypophonia), hoarseness, a harsh vocal quality, breathiness, reduced pitch, consonant imprecision, distorted vowels, inappropriate pauses, vocal tremor, and short rushes of speech referred to as festinations (Tjaden, 2008). The harsh and breathy vocal quality in the speech of individuals with PD is caused by an inability of the vocal folds to adduct completely, allowing air to leak through. When asked to produce a rapid syllabic sequence, individuals with PD will often produce blurring and imprecise articulation of phonemes with variable rates. Prosody is also affected, causing a monopitch and monoloud quality and thus reduced linguistic stress. A study by Kim (1994) found that the acoustic variable contributing the most to the monotone quality in the speech of individuals with PD was fundamental frequency (F_0), having a greater effect than intensity and duration. As a result, Kim explained, “Manipulating mainly F_0

feature [sic] might have a generalized effect on other prosodic dimensions such as monoloudness or even the degree of severity" (p. 178).

There is currently no cure for PD and most individuals live years with the disease. A frequently used approach in the treatment of hypokinetic dysarthria in individuals with PD is the Lee Silverman Voice Treatment (LSVT) which teaches the speaker to increase their overall speaking loudness (Tjaden, 2008). This increased loudness results in many positive side effects, including more precise articulation and a slowed rate of speech, both of which contribute to increased intelligibility. Individuals with PD are often unaware of their decreased vocal loudness, and LSVT helps the individual recognize that there is room for them to increase their loudness, thus helping them to realize the benefits of greater vocal effort, which include increased intelligibility.

Other dysarthria treatment approaches include speaker-oriented treatments focusing on behavioral and compensatory strategies to increase speech intelligibility, as well as communication-oriented strategies focusing on teaching other factors impacting understanding between communication partners, such as using gestures, identifying the topic of conversation, and asking if the message was understood (Yorkston, Beukelman, Strand, & Hakel, 2010). These strategies are often taught in a controlled clinical setting, while the true value and importance of using them lies in natural settings. These everyday situations often involve many distractions and most of our speech is done while multitasking. "The importance of practicing new approaches to talking away from the formal clinical setting is especially important for persons with PD, as poor generalization from the clinic to more naturalistic, conversational situations has long been a concern in this population" (Tjaden, 2008, p. 5).

Speech in Aging

Aging is a natural process and part of life. Age-related changes typically manifest as decreases in fine and gross motor function. As people age, their bodies tend to stiffen and weaken, resulting in a slowing of movement. This stiffness, weakness, and slowing will also have an impact on communication. Normal aging affects many aspects of communication, including hearing, language, and speech. The vocal mechanism is affected by aging of the larynx which may cause weakness of the voice, decreased intensity, variations in pitch, tremor, and hoarseness. Pitch will naturally increase slightly in males with advanced age, whereas pitch will decrease somewhat in elderly females. Unsteadiness of the voice may occur due to a natural decrease in neuromuscular control over the muscles supporting the function of the larynx. Speech tends to be produced more slowly and precision of articulation generally decreases (MacPherson, 2013).

Many of these changes in speech due to natural aging overlap with the effects of PD on speech. Aging is not a cause of PD although it is more common in the elderly. Because PD affects individuals later in life, it is important to differentiate between the natural aging process and the effects of PD on speech. One important distinction is that natural speech changes resulting from aging are usually subtle and noticeable only to a professional. MacPherson (2013) states, "Greater declines in aspects of speech production occur with advanced old age and reduced health status. Thus, although intelligibility is typically maintained in healthy older adults, underlying changes in speech production and speech motor control are evident" (p. 5). As such, it is important to note that these changes will not have a profound impact on the individual's activities of daily living, whereas the effects of PD on speech can greatly impact the individual and their ability to communicate effectively.

Speech and Divided Attention

Multitasking in life is common and it could be argued that it has become the rule rather than the exception. However, multitasking does not come without its costs, one of which being a decline in performance in one or all of the tasks being executed. Not only does multitasking affect the youngest and healthiest of individuals, but as individuals age we see a decline in their ability to multitask as effectively as their younger counterparts (Chen et al., 1996). Furthermore, when an individual with impaired neurological functioning multitasks, such as an individual with PD, there is an even greater breakdown in their ability to do one or all of the tasks effectively (Ho, Iansek, & Bradshaw, 2002). For example, in a study by Ho et al. (2002), participants with PD demonstrated a greater deterioration of speech when performing a concurrent visuo-manual task as compared to the control groups. How then, is speech compromised when an individual with PD has their attention drawn to a second task while talking, and how much of the breakdown in their speech is attributable to the effects of natural aging?

Older adults generally have a greater degree of divided attention interference than younger adults. Multiple studies have examined the specific breakdowns that occur when older adults multitask. Chen et al. (1996) found that although both older and younger adults were more likely to make contact with obstacles while walking during a divided attention task, it was also found that the older adults were at a significantly greater risk for contact than the younger adults. McDowd and Craik (1988) found that beyond the age effects on multitasking, older adults experienced greater interference when the tasks increased in complexity. One possible explanation for this is “that mental operations take longer to perform with increasing age and that this behavioral slowing is amplified as the task involves a greater number of operations”

(McDowd & Craik, 1988, p. 279). This demonstrates the vulnerability of older adults not only to multitasking, but to increasingly complex tasks as well.

In a meta-analysis of 33 dual-task studies, Verhaeghen, Steitz, Sliwinski, and Cerella (2003) showed that there was still an age-related effect when multitasking even after controlling for task complexity and performance as well as age-related declines in the component tasks. Regarding this meta-analysis along with other studies of divided attention, Bailey and Dromey (2015) explained, "In terms of models of attention, the findings of these studies could be interpreted as a decline in available attentional resources or a decrease in efficiency of the executive control process(es) in older adults compared with younger adults" (p. 1638). This is one of several potential explanations why older adults are more susceptible to breakdowns in performance when multitasking.

In a study examining the relationship between age and increased cognitive demands and autonomic arousal on speech, MacPherson (2013) stated, "the observed age-related differences in the effects of increased cognitive load and autonomic arousal on speech motor performance indicate that aging may affect the relationship between cognitive, autonomic, and speech motor processes, contributing to speech motor systems that are more susceptible to destabilization in older adults" (p. xvii). Another possible explanation for this aging effect on multitasking may be the natural aging process of the motor control system. The decline in strength, coordination, balance, and an increase in reaction time can affect the efficiency with which multitasking occurs (Bailey & Dromey, 2015). This affects both speech and nonspeech tasks. In this study we examine the degree to which a dual-task condition of walking while talking affects speech in terms of its rate, the proportion of time speaking versus pausing, overall intensity, intensity variability, and F_0 variability. These effects are compared between healthy older adults and adults with PD to determine any variation between the two groups.

How then might interference be manifest in individuals with PD during a multitasking condition? Galletly and Brauer (2005) examined how executing a calculation task, a motor task, and a language task while walking affected gait in individuals with PD. They explained, "When another task is performed concurrently with the motor task, performance of either the motor or the concurrent task often drops as there are insufficient cognitive resources to perform both tasks optimally" (Galletly & Brauer, 2005, p. 175). After accounting for variations in stride length at baseline, a difference was found between the individuals with PD and the age-matched healthy adults in stride length when completing the language and calculation tasks, thus demonstrating the effects of PD in certain types of dual-task conditions. In another study, Sharpe (1996) sought to determine if there was a difference between individuals with PD and healthy older adults in whether they were able to divide their attention between two concurrently presented auditory stimuli. The results of this study showed that the individuals with PD, whose duration of disease ranged from 1-11 years, identified the target word less often than the neurologically typical control group, indicating that individuals with PD may have limited attentional capacity even during the earliest stages of the disease.

Ho et al. (2002) examined speech motor performance in a dual-task experiment, finding that individuals with PD are at a disadvantage compared to healthy adults. They summarized, "our results suggest that hypophonic PD patients show an additional deterioration of volumetric and temporal deficits in speech, when attentional resources are reduced by a distractor task. This is consistent with the consequence of reduced attention in other complex movements of the upper and lower limbs, in hypokinetic PD patients" (p. 46). Aspects of cognition crucial to speech and multitasking are also affected in PD. In a study of cognitive and gait performance during divided attention tasks, Stegemöller et al. stated, “Cognitive impairments in PD manifest as deficits in speed of processing, working memory, and executive function and attention abilities (2014, p. 757). They reported the importance of these cognitive functions when individuals with PD are performing a task such as walking without a concurrent task causing an increase in the cognitive load. The study by Stegemöller et al., among others, indicates that dual-task conditions have an effect on cognition as well as gait performance. All of these studies that have examined dual-task conditions involving gait performance, auditory-perceptual performance, and speech motor performance demonstrate further deterioration of performance when an older adult is compromised neurologically by PD.

LaPointe et al. (2010) studied the effect of talking while walking on gait performance, specifically determining if individuals with PD were at a greater risk for falls. They found, “elderly individuals with neurological compromise may be at a greater risk. These results suggest that it might be prudent for healthcare professionals and caregivers to alter expectations and monitor cognitive-linguistic demands placed on these individuals while they are walking” (p. 459). When targeting speech during treatment for individuals with PD it is important to be sensitive to their lifestyle and needs beyond the clinic room doors. As such, it is important to consider how we can better treat our clients and provide them with strategies useful in contexts where their attention is divided, such as conversing with a friend while on a walk. In this study we seek to examine specific ways in which speech is affected in individuals with PD when presented with a divided attention task of talking while walking at two levels of complexity. It is important to understand dual task interference in individuals with Parkinson’s disease and how it can influence how clinicians work with this population in terms of providing effective therapy.

Method

This work is a part of a larger study which was conducted in the Motion Capture Core Facility (MOCAP) at the University of Utah. The primary aim of the larger study was to collect gait and stride data. The speech samples included in the study were collected by Lorinda Smith, a doctoral candidate at the University of Utah. The samples were released with University of Utah Institutional Review Board (IRB) approval to Brigham Young University for the study of various speech parameters.

Participants

Three groups participated in the study with a total of 27 individuals. The three groups included 8 individuals with PD, 12 neurologically healthy older adults, and 7 neurologically healthy younger adults. Inclusion criteria for the participants with PD included a medically confirmed diagnosis of mild to moderate idiopathic PD, at least 40 years of age, and the ability to participate. Individuals with PD who were using dopamine replacement drugs were tested 1 to 1.5 hours after taking the medication. The healthy older participants were age- and gender-matched to the participants with PD. All participants were cleared medically to participate due to a minimal risk of falling during balance testing. Exclusion criteria for the participants included health conditions such as cardiovascular or orthopedic concerns which would inhibit the ability to safely participate, lower limb neuropathy, prior surgical treatment for PD, cognitive impairment limiting participation, uncorrected vision or hearing loss limiting participation, and presence of freezing episodes while on medication. Participants were recruited from the Parkinsonism Exercise Program at the University of Utah Rehabilitation and Wellness Clinic.

Instruments

For the conditions requiring a walking task, a Bertec side-by-side dual-belt treadmill (Columbus, Ohio) with removable safety rails on the front and sides was used. All participants wore a tether release system throughout testing for injury prevention in case of a fall. The spoken language samples were recorded into a computer with Audacity software (http://audacity.sourceforge.net/) via a head-mounted USB microphone. Marker-based gait data were collected for the larger study using a VICON Motion Analysis System (Oxford, United Kingdom) and are not applicable to the focus of the current study.

Procedure

All participants provided demographic information and signed a consent form prior to testing. Each participant was presented with a list of conversational topics to choose from during testing. The complete list of conversational topics can be found in Appendix C. When the participant had exhausted a topic they would say “next” and the test administrator would present the next conversational topic.

Each participant produced a spontaneous monologue under three conditions of increasing difficulty: talking while standing, talking while walking on a treadmill, and talking while walking on a treadmill while stepping over obstacles which had been randomly placed on it. These obstacles were about the size and shape of a shoebox. Each participant’s speech was recorded during all three of the conditions.

Data Analysis

Speech measures in all three conditions were compared to quantify the impact of divided attention on the participants. Speech recordings were analyzed using the Praat software program (version 5.4; Boersma & Weenink, 2014). Pauses between topics, experimenter speech, and nonspeech behaviors such as laughing and coughing were trimmed from the recordings before analysis.

Acoustic measures of speech rate, speaking versus pausing time, overall intensity, and intensity and F_0 variability were analyzed. F_0 was measured using the mean and standard deviation in the recording. The F_0 range was adjusted in Praat in order to avoid tracking errors. Due to the difference in F_0 in males and females, the standard deviation values in Hz were converted to semitones using a spreadsheet equation. Intensity was measured using the mean and standard deviation from the recording as well. A dB floor was selected based on the level of the softest speech sounds in the recording in order to avoid analyzing the intensity level during nonspeech sounds or pauses. The intensity listing in Praat was exported as a comma separated values file (CSV) and then imported into a custom Matlab application (version 9.0; The Mathworks, Inc., 2016) to determine the mean and standard deviation above the dB floor. The ratio of speaking rate versus pausing time was expressed as a proportion with 1.0 representing all speaking and no pausing, .50 representing 50% speaking and 50% pausing, and so on. The speaking and pausing ratio was computed using a custom Matlab application which recognized pauses as silences greater than 200 ms. The application also normalized the file intensity to 100. The determined threshold was 10% of the normalized max, with anything above defined as speaking and anything below defined as pausing.

Results

Changes in the dependent variables across the conditions of standing, walking, and obstacle walking were tested using SPSS 25 software. A repeated measures analysis of variance (RM-ANOVA) was completed, with concurrent contrasts to reveal which conditions differed from the baseline condition of standing. The statistical testing compared walking with standing and obstacle with standing. Between-subjects factors included group and gender and post-hoc testing (Tukey HSD) and allowed further examination of significant differences. The results did not reveal any significant interactions of condition with gender. However, the anticipated male/female between subjects differences in the fundamental frequency were significant, and therefore, the data are reported separately for men and women. In cases where the assumption of sphericity was violated, as indicated by a significant result in Mauchly's test, non-integer degrees of freedom were used, as specified by the Huynh-Feldt correction.

Table 1

Descriptive Statistics for All Dependent Variables for the Healthy Young Male Speakers

	Stand		Walk		Obstacle	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Median F_0	97.82	10.96	103.04	9.06	106.05	15.32
Mean F_0	101.29	11.05	106.16	9.53	109.46	15.00
STSD	2.67	0.69	2.38	0.31	2.62	0.50
Min F_0	70.32	11.17	71.62	11.23	70.92	9.32
Max F_0	211.62	17.00	189.59	11.96	220.30	26.86
Mean dB	63.75	2.47	66.93	1.49	68.06	1.78
SD dB	5.46	0.74	5.57	1.14	6.08	0.93
Speak/Pause	0.736	0.086	0.793	0.108	0.736	0.064
Speech Rate	42.00	5.48	41.50	6.25	32.00	6.38

Note. M = Mean, F_0 = fundamental frequency, STSD = semitone standard deviation, dB = decibel, *SD* = standard deviation

Table 2

Descriptive Statistics for All Dependent Variables for the Healthy Young Female Speakers

	Stand		Walk		Obstacle	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Median F_0	190.38	18.88	192.76	21.84	209.64	22.63
Mean F_0	199.93	18.16	201.98	21.27	217.47	18.48
STSD	2.73	0.19	2.62	0.19	2.57	0.64
Min F_0	138.55	9.58	147.73	6.11	141.67	7.67
Max F_0	364.81	10.21	364.10	6.11	376.57	11.19
Mean dB	64.59	3.04	66.39	2.85	69.06	2.06
SD dB	5.33	0.38	5.67	0.49	5.84	0.27
Speak/Pause	0.842	0.052	0.784	0.125	0.829	0.017
Speech Rate	38.33	9.45	40.33	10.02	36.00	11.53

Table 3

Descriptive Statistics for All Dependent Variables for the Healthy Older Male Speakers

	Stand		Walk		Obstacle	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Median F_0	118.76	14.65	123.69	13.15	131.48	12.26
Mean F_0	121.91	14.89	126.66	13.67	134.74	12.80
STSD	2.52	0.43	2.42	0.35	2.67	0.31
Min F_0	76.54	9.25	76.86	5.74	77.50	11.16
Max F_0	247.87	17.92	247.44	14.73	258.80	31.05
Mean dB	63.34	3.12	65.82	4.34	66.86	4.49
SD dB	5.31	1.17	6.19	1.54	6.46	1.23
Speak/Pause	0.775	0.072	0.758	0.064	0.703	0.112
Speech Rate	32.00	7.62	34.14	6.77	34.43	8.92

Table 4

Descriptive Statistics for All Dependent Variables for the Healthy Older Female Speakers

	Stand		Walk		Obstacle	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Median F_0	196.45	23.27	209.25	20.63	214.05	29.44
Mean F_0	202.95	21.99	214.48	19.36	220.02	26.96
STSD	2.58	0.58	2.58	0.47	2.76	0.46
Min F_0	130.11	12.68	130.82	10.19	131.78	13.77
Max F_0	355.57	49.40	354.72	51.69	359.12	46.96
Mean dB	66.01	3.05	66.79	1.96	67.30	2.35
SD dB	6.47	0.93	6.79	1.51	6.94	1.55
Speak/Pause	0.754	0.058	0.722	0.151	0.72	0.049
Speech Rate	35.60	5.68	35.40	6.58	35.20	9.45

Table 5

Descriptive Statistics for All Dependent Variables for the Male Speakers with Parkinson's Disease

	Stand		Walk		Obstacle	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Median F_0	142.84	11.52	161.51	19.17	165.33	18.11
Mean F_0	145.23	11.58	163.02	17.90	166.64	17.91
STSD	2.46	0.34	2.65	0.38	2.42	0.06
Min F_0	94.20	7.83	96.60	7.78	93.54	10.35
Max F_0	248.16	30.76	261.90	30.01	269.69	25.21
Mean dB	68.19	2.84	72.63	4.18	71.51	3.91
SD dB	4.99	1.43	5.50	0.70	5.74	1.41
Speak/Pause	0.701	0.088	0.701	0.073	0.655	0.081
Speech Rate	37.17	12.16	36.17	13.50	40.33	6.68

Table 6

Descriptive Statistics for All Dependent Variables for the Female Speakers with Parkinson's Disease

	Stand		Walk		Obstacle	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Median F_0	165.41	5.54	176.02	2.64	183.42	14.45
Mean F_0	170.50	3.13	178.34	3.32	186.22	14.76
STSD	1.96	0.09	1.63	0.42	1.63	0.57
Min F_0	129.86	24.16	132.08	24.09	133.44	28.10
Max F_0	264.52	47.33	259.08	41.68	284.44	40.67
Mean dB	57.41	1.38	61.28	2.40	62.79	2.00
SD dB	4.01	0.25	4.60	0.10	4.19	0.04
Speak/Pause	0.722	0.018	0.672	0.038	0.726	0.071
Speech Rate	18.50	3.54	29.00	19.80	27.00	8.49

The median F_0 differed significantly across the conditions of standing, walking, and obstacle, $F(2, 42) = 42.712$, $p < .001$, effect size (ES) .670. The within-subjects contrast showed a significant difference between the conditions of standing and walking, $F(1, 21) = 34.369$, $p < .001$, ES .621, and between the conditions of standing and obstacle, $F(1, 21) = 63.697$, $p < .001$, ES .752. As seen in Figure 1, the median F_0 increased from standing to walking and even more between the conditions of standing to obstacle. The three groups did not differ significantly from each other at the $p < .05$ level, although the male HO and PD groups produced higher median F_0 values than the HY group. The female participants with PD produced lower median F_0 values than the female HO and HY groups.

Table 7

Number of Participants in Each Group

	HY	HO	PD
Male	4	7	6
Female	3	5	2

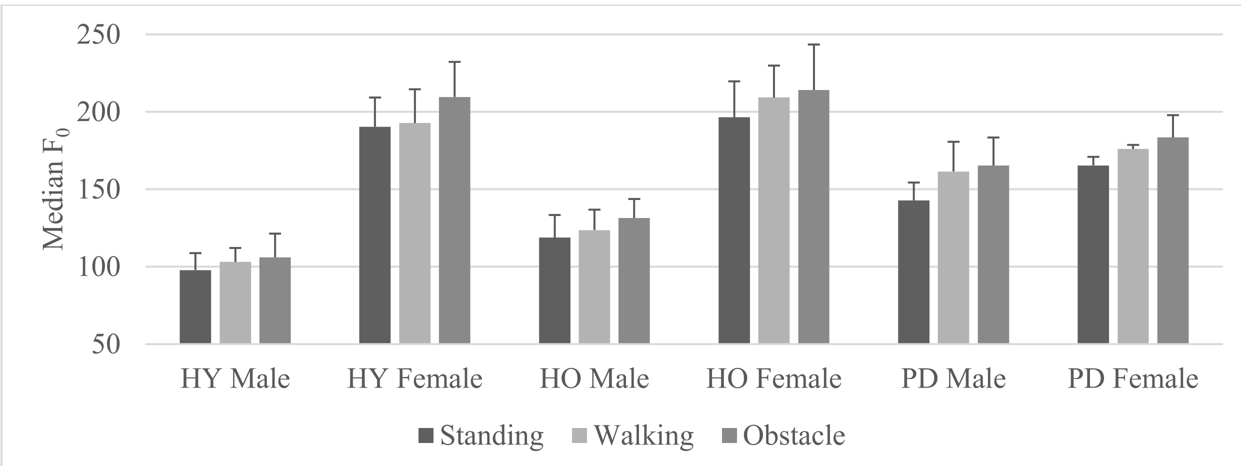

Figure 1. Median F_0 and *SD*.

The mean F_0 differed significantly across the conditions of standing, walking, and obstacle, $F(2, 42) = 42.589$, $p < .001$, ES .670. The within-subjects contrast showed a significant difference between the conditions of standing and walking, $F(1, 21) = 33.010$, $p < .001$, ES .611, and between the conditions of standing and obstacle, $F(1, 21) = 61.028$, $p < .001$, ES .744. As seen in Figure 2, the mean F_0 increased from standing to walking. The increase in the mean F_0 was even greater between the conditions of standing and obstacle. There were no significant differences between the three groups, although the male HO and PD groups produced a higher mean F_0 than the male HY group. The female participants with PD produced a lower mean F_0 than the female HY and HO groups.

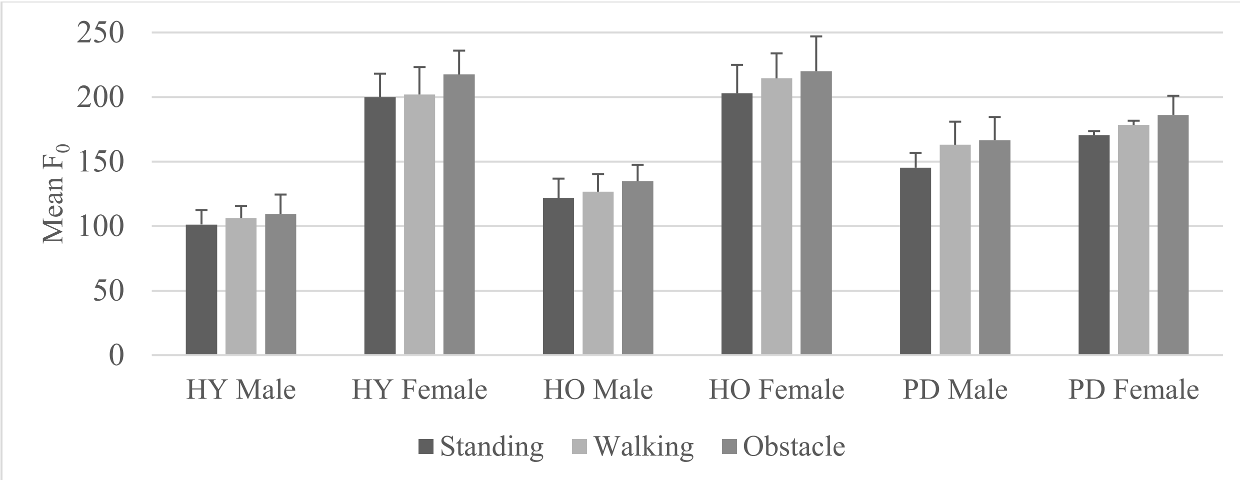

Figure 2. Mean F_0 and *SD*.

The semitone standard deviation for F_0 did not differ significantly as a main effect. There were no significant within-subject contrasts for semitone standard deviation. As seen in Figure 3, although not statistically significant, the female Parkinson's group reflects more monotonous speech across all three conditions as compared to the other groups. Regarding this difference, it is important to note that there were two participants in the female PD group.

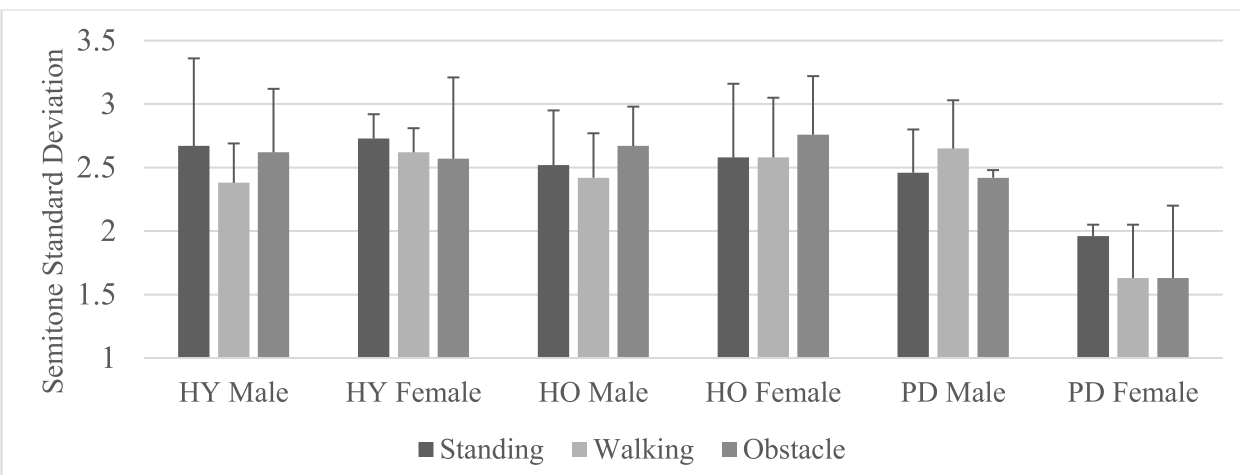

Figure 3. F_0 semitone standard deviation.

The minimum F_0 across the three conditions of standing, walking, and obstacle did not differ significantly as a main effect. However, the within-subjects contrast showed a significant difference between the conditions of standing and walking, $F(1, 21) = 9.157$, $p < .006$, ES .304.

As seen in Figure 4, min F_0 was highest for the males with PD and lowest for HY males. The females in the HY group had the highest min F_0.

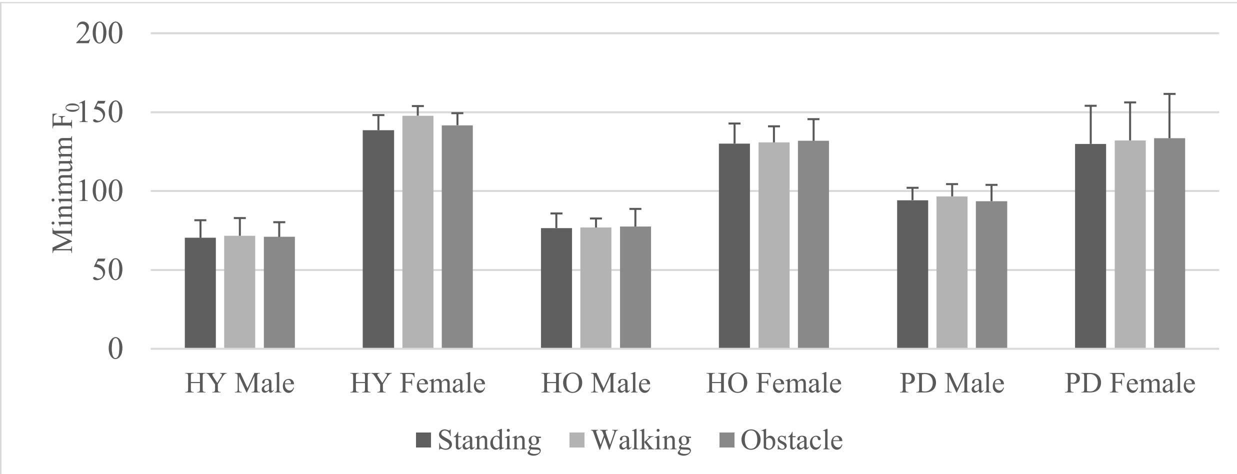

Figure 4. Minimum F_0 and *SD*.

The maximum F_0 differed significantly across the three conditions, $F(1.773, 37.228) = 11.1888$, $p < .001$, ES .348. The within-subjects contrast showed a significant difference between the conditions of standing and obstacle, $F(1, 21) = 11.100$, $p < .003$, ES .346. There were also significant differences between standing and walking by group, $F(2, 21) = 4.687$, $p < .021$, ES .309, and between standing and walking by gender and group, $F(2, 21) = 7.334$, $p < .004$, ES .411. As seen in Figure 5, the max F_0 increased from standing to obstacle. The increase between the conditions was greatest for the speakers with PD. There were no significant differences between the three groups, although among the males, the HY males had the lowest maximum F_0, while the males with PD had the highest maximum F_0. Among the females, the HY females had the highest maximum F_0, while the females with PD had the lowest maximum F_0.

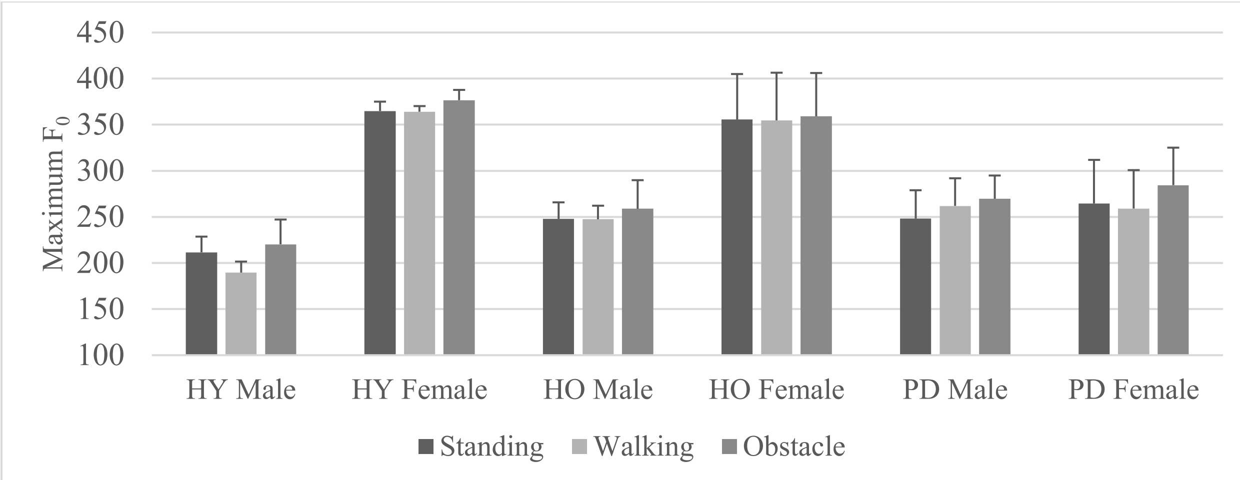

Figure 5. Maximum F_0 and *SD*.

The mean dB differed significantly across the conditions of standing, walking, and obstacle, $F(2, 42) = 27.573$, $p < .001$, ES .568. The within-subjects contract showed a significant difference between the conditions of standing and walking, $F(1, 21) = 20.584$, $p < .001$, ES .495, and between the conditions of standing and obstacle, $F(1, 21) = 57.059$, $p < .001$, ES .731. As seen in Figure 6, the PD group had the greatest increase in mean dB from standing to walking, followed by the HY group. Due to lack of dB calibration, comparison across groups as well as group and gender interactions cannot be made. The dB measure is relative rather than absolute, and can thus only be compared within-subjects.

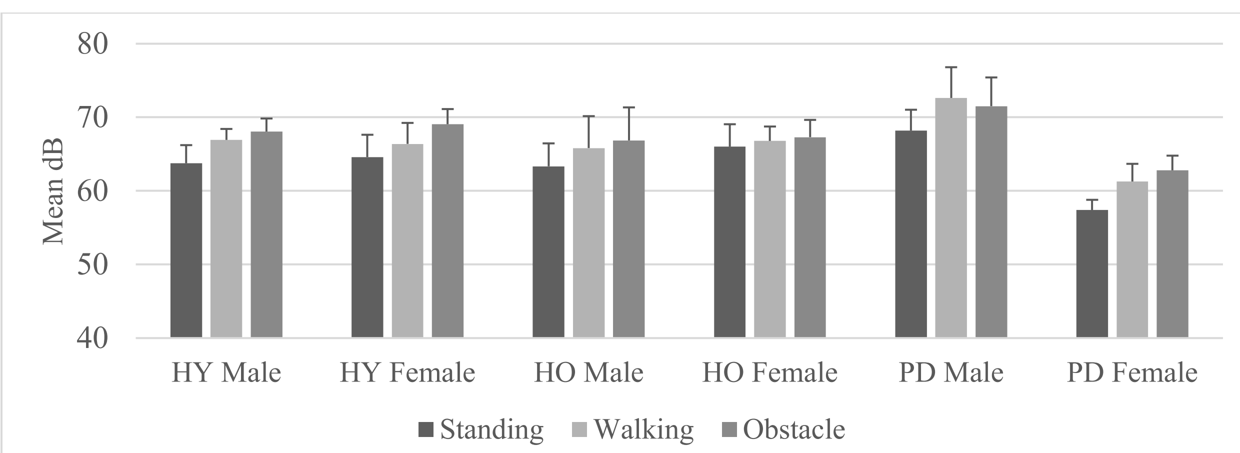

Figure 6. Mean dB.

The dB standard deviation differed significantly across all three of the conditions, $F(2, 42) = 7.961$, $p < .001$, ES .275. The within-subjects contrast showed a significant difference between the conditions of standing and walking, $F(1, 21) = 7.705$, $p < .011$, ES .268, and between standing and obstacle, $F(1, 21) = 13.807$, $p < .001$, ES .397. As seen in Figure 7, all groups demonstrated an increase in intensity and variability between the conditions of standing and walking. All groups with the exception of the females with PD demonstrated an increase in intensity variability between walking and obstacle, with the females with PD showing a decrease from walking to obstacle. It is important to note that the females with PD also had the lowest dB *SD*, indicating more monoloud speech across all three conditions as compared to the other groups. This result may be influenced by the small sample of females with PD (n=2) in the study.

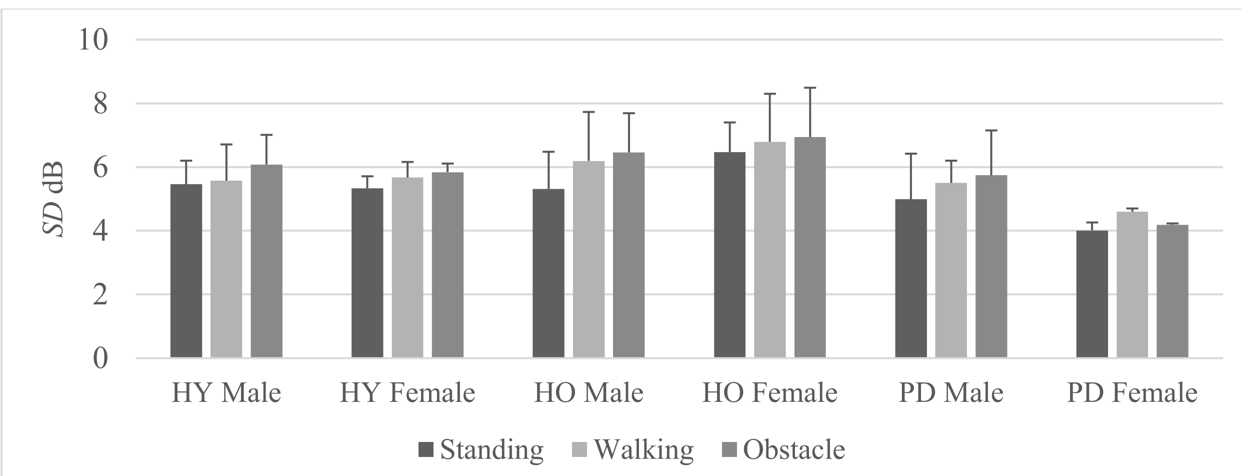

Figure 7. dB standard deviation.

The speaking/pausing time ratio did not differ significantly as a main effect and there were no significant within-subject contrasts. The response to the increasingly complex conditions was not uniform across the groups.

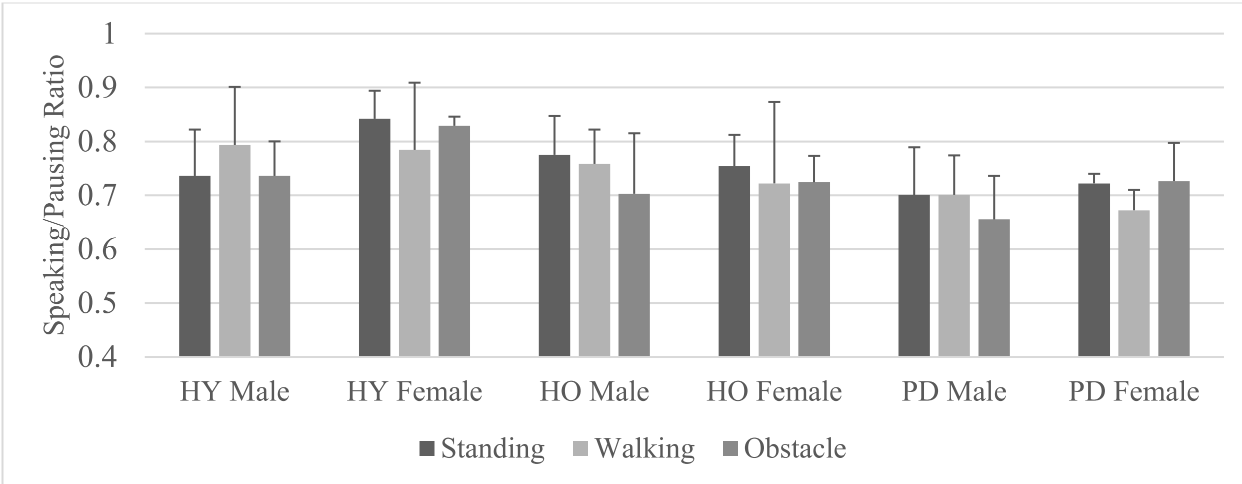

Figure 8. Speaking/pausing ratio.

The speech rate of the speakers did not differ significantly as a main effect and there were no significant within-subject contrasts. As seen in Figure 9, the female PD group showed the greatest variation in speech rate across the three conditions, with rate increasing from standing to walking and obstacle. The male PD group also showed an increase in speech rate from standing to obstacle. The healthy young male and female groups showed a decrease in speech rate from standing to obstacle with greater variation. The healthy older male and female groups showed less variation, with the HO male group increasing in speech rate across the three conditions and the HO female group decreasing slightly across the three conditions.

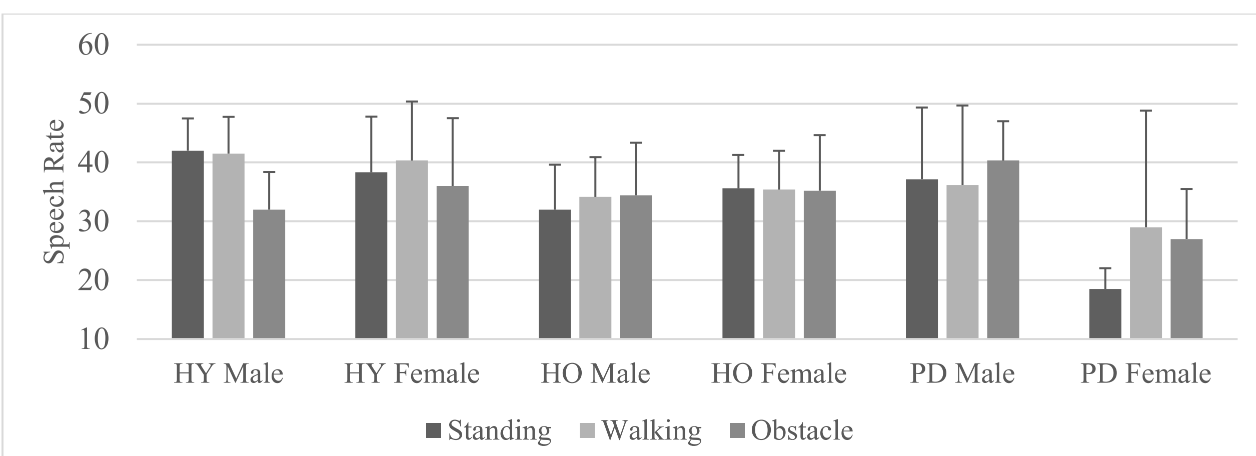

Figure 9. Speech rate.

Discussion

This study examined the effects of divided attention on several acoustic measures of speech in individuals with PD and in age-matched and younger control groups. It was hypothesized that speech performance would be negatively impacted as the divided attention task complexity increased across the three conditions of standing, walking, and walking over obstacles. Furthermore, it was predicted that these measures would be more substantially impacted for the group with PD due to their impaired neurological function. In a study by Ho et al. (2002), it was found that individuals with PD demonstrated a decreased ability to allocate attentional resources to multiple tasks at one time. This caused the speech of those with PD to be negatively impacted during multitasking as compared to an age-matched control group. Kemper et al. (2010) conducted a study comparing dual-task performance in healthy young and healthy old participants. The authors of this study found that the older adults were more vulnerable than the younger adult group to breakdowns in speech and language as task complexity increased. Similarly, Verhaeghen et al. (2003) reported that performance costs while multitasking were larger and more significant for older adults as compared to younger adults. Regarding performance difference on divided attention tasks between adults with PD and neurologically healthy adults, a study by Sharpe (1996) found that individuals with PD had limited attentional capacity while multi-tasking as compared to neurologically healthy adults. Therefore, for the purposes of the current study it was hypothesized that the HY group would experience less dual-task interference than the older adults and the participants with PD would experience the most dual-task interference.

Median and mean F_0 increased across the progressively complex task conditions for all three groups. The females in the HO and PD groups showed a trend for lower F_0 than the younger women; the median and mean F_0 values were lower for the females with PD compared to the women in the HY and HO groups. Eadie (2000) discussed changes in F_0 across the lifespan, stating that female F_0 remains fairly constant from the twenties to approximately age 50 when it drops, possibly as a result of hormonal changes. Furthermore, women with PD tend to demonstrate perceptual voice characteristics of reduced variation in vocal F_0 and a tendency to be more monopitch (Tjaden, 2008). In the current study, the differences between the males in the HO and PD groups were consistent with trends for increased F_0 across the lifespan, with median and mean F_0 highest for the males in the PD group, followed by the males in the HO group compared to the males in the HY group. While female F_0 has a tendency to decrease with age, male F_0 tends to increase gradually from middle age onward, likely due to muscle atrophy and/or increased vocal fold stiffness (Eadie, 2000). The current study resulted in the highest minimum and maximum F_0 for the males with PD followed by HO males, again consistent with PD and age-related findings in the literature for male speakers (Eadie, 2000; Tjaden, 2008). Minimum and maximum F_0 were highest for the females in the HY group, followed by the women in the HO group for the maximum F_0, with the females in the PD group producing the lowest maximum F_0. The results of F_0 semitone standard deviation showed greater monotony in speech among the females in the PD group, although the small sample size (n=2) may have impacted these results. These observations are consistent with hypotheses that speakers with PD would produce less F_0 variability as task complexity increased across the conditions, as previously found in a study by Kim (1994).

Mean dB and dB standard deviation measures showed an increase across the three conditions, reflecting louder speech with greater loudness variability as task complexity increased. The group with PD, the HY, and the HO groups had similar performance trends across the conditions of standing and walking, demonstrating an overall increase. Although not found in results of this study, it was anticipated that the participants with PD would demonstrate less of an increase in dB and less dB variability as compared to the HO and HY control groups due to the monoloud characteristic of speech in PD (Tjaden, 2008).

Speaking and pausing time demonstrated differing responses to increased complexity between the groups without a consistent trend. The expected trend was to see an increase in overall pausing during the divided attention tasks as complexity increased. The measures for speech rate produced similar results, with differing responses and no trend demonstrated across the groups. Ho et al. (2002) found that individuals with PD demonstrated a reduced speech rate as well as increased speech pause time during divided attention tasks compared to age-matched healthy older adults. As a result, for the purposes of this study it was hypothesized that speech rate would decline for the HO and PD groups as compared to the HY group.

The results of the current study are consistent with the findings of MacPherson (2013) regarding aging and its effects on speech, including subtle changes in parameters of speech which do not impact intelligibility. Differences in fundamental frequency between the groups were consistent with the natural aging process of males increasing in F_0 with age, and females decreasing in F_0 with age (Eadie, 2000). For this study, it was hypothesized that speech rate would decline with age, although the results revealed no significant effects. Overall, the differences between the HY and HO group demonstrated expected trends consistent with previous findings. Increasing the divided attention task complexity did not significantly impact the HO group more than the HY group in this study. In previous studies, HO adults have been found to be more vulnerable than their younger counterparts to breakdowns in speech and language as demands increase (Kemper et al., 2010).

Tjaden (2008) described characteristics of speech in individuals with PD, which include an increased rate of speech, decreased loudness, reduced pitch, and inappropriate pauses. In the current study, the group with PD demonstrated no statistically significant differences from the other groups regarding rate of speech or increased pausing time. The females in the group with PD did show a trend for reduced F_0 as compared to the females in the HO group. Greater monotony of speech was expected, although the results did not reveal statistically significant effects.

A study by Chen et al. (1996) examined whether dividing attention during an obstacle walking task would affect young adults differently than healthy older adults. The results of the study (Chen, 1996) found that all groups reacted to the divided attention task by slowing their walking rate. The effects of the increasingly complex divided attention tasks in the current study were consistent with these findings by Chen. In the current study, all three groups demonstrated changes in the speech parameters of F_0 and dB as task complexity increased, although no significant differences between the three groups were found. Previous studies (McDowd & Craik, 1988) have found older adults to be more vulnerable to breakdowns during multitasking, although the current study did not reveal significant differences in performance between the HO and HY groups.

Limitations of the Current Study and Directions for Further Research

A weakness of this study is the unequal numbers of participants from each of the three groups, as well as unequal numbers of men and women within each group. Findings regarding the differences between the individuals with PD and the HY and HO control groups might have been different with an equal number of participants in each group, including equal numbers of male and female participants within each group. It is important to consider the results of the current study in the context of having two female participants with PD with more female participants in the HY and HO groups. Further studies could explore effects of divided attention on speech in PD with an equal sample size across groups and gender.

Kinematic gait analyses of walking and obstacle walking were not included as part of the present study. The Department of Physical Therapy at the University of Utah has the data for these measures, although they have not yet been analyzed. These measures may have provided valuable insight in the current study regarding allocation of attentional resources during a divided attention task. Concurrent walking and talking performance in individuals with PD is important to understand in order to minimize fall risks for these patients. We are unable to determine how the participants in this study allocated their attentional resources in order to overcome the distractions of walking and obstacle walking. Further studies could explore adding further nonspeech measures in order to examine how individuals compensate for an increase in task complexity, as well as examining differences between HO and HY groups.

An additional limitation of the present study was the inability to compare mean dB measures across groups due to lack of calibration at the time the data were collected. Previous studies have found reduced intensity and monoloudness in the speech of individuals with PD as compared to HO control groups (Kim, 1994; Tjaden, 2008). Due to the lack of calibration in this study, we were unable to determine if there were group effects for intensity.

Conclusion

This study examined the effects of divided attention on measures of F_0, intensity, speech rate, and speaking versus pausing time in individuals with Parkinson's disease. It is important to consider the influence of natural aging and increased task complexity on the speech performance of individuals with PD. The results of this study confirm that natural aging has an effect on performance during divided attention tasks. This suggests that aging plays a role in performance on speech tasks, affecting variables such as F_0 and F_0 variability in HO adults more so than HY adults.

These findings have clinical implications for the treatment of patients with communication disorders, including patients with PD. Therapy settings generally control distracting variables by holding treatment sessions in private rooms free from outside noise and visual distractions. While this controlled setting may provide patients with an ideal environment for communication, it does not reflect everyday situations which are often distracting and require multitasking. Providing therapy in a controlled setting to patients with communication disorders, including those associated with PD, may limit the extent to which the patient can generalize learned skills to typical situations. The findings of the current study demonstrate that HO adults and individuals with PD are affected to a greater extent than their younger counterparts when multitasking. As such, it may be helpful to incorporate divided attention and multitasking situations into therapy in order to provide patients with opportunities for greater success in communicating in everyday situations outside of therapy.

References

Bailey, D. J., & Dromey, C. (2015). Bidirectional interference between speech and nonspeech tasks in younger, middle-aged, and older adults. *Journal of Speech, Language and Hearing Research*, 1637-1653. doi:http://dx.doi.org/10.1044/2015_JSLHR-S-14-0083

Chen, H.-C., Schultz, A., Ashton-Miller, J., Giordani, B., Alexander, N., & Guire, K. (1996). Stepping over obstacles: Dividing attention impairs performance of old more than young adults. *Journals of Gerontology*, M116-M122.

Eadie, T. L. (2000). Characteristics of the aging female voice. *Journal of Speech-Language Pathology and Audiology/Revue d'Orthophonie Et d'Audiologie*, 162-179.

Galletly, R., & Brauer, S. G. (2005). Does the type of concurrent task affect preferred and cued gait in people with Parkinson's disease? *Australian Journal of Physiotherapy*, 175-180.

Ho, A. K., Iansek, R., & Bradshaw, J. L. (2002). The effect of a concurrent task on Parkinsonian speech. *Journal of Clinical and Experimental Neuropsychology, 24*, 36-47.

Kemper, S., Schmalzried, R., Hoffman, L., & Herman, R. (2010). Aging and the vulnerability of speech to dual task demands. *Psychology and Aging*, 949-962.

Kim, H. (1994). *Monotony of speech production in Parkinson's disease: Acoustic characteristics and their perceptual relations* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Full Text; ProQuest Dissertations & Theses Global. (Order No. 9508857).

LaPointe, L. L., Stierwalt, J. A. G., & Maitland, C. G. (2010). Talking while walking: Cognitive loading and injurious falls in Parkinson's disease. *International Journal of Speech Language Pathology*, 455-459. doi: http://dx.doi.org/10.3109/17549507.2010.486446

MacPherson, M. K. (2013). *Cognitive and autonomic factors in speech motor control: Effects of the aging process* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Full Text; ProQuest Dissertations & Theses Global. (Order No. 3591545).

McDowd, J. M., & Craik, F. I. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance*, 267-280.

Sharpe, M. H. (1996). Is there a divided attention deficit in patients with early Parkinson's disease? *Cortex*, 747-753. doi:10.1016/S0010-9452(96)80044-X

Stegemöller, E.L., Wilson, J. P., Hazamy, A., Shelley, M. C., Okun, M. S., Altmann, L. J. P., & Hass, C. J. (2014). Associations between cognitive and gait performance during single- and dual-task walking in people with Parkinson’s disease. *Physical Therapy*, 757-66. doi:10.2522/ptj.20130251

Tjaden, K. (2008). Speech and swallowing in Parkinson’s disease. *Topics in Geriatric Rehabilitation*, 115–126. doi:10.1097/01.TGR/0000318899.87690.44

Verhaeghen, P., Steitz, D.W., Sliwinski, M.J., Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging*, 443-460.

Yorkston, K. M., Beukelman, D.R., Strand, E.A., Hakel, M. (2010). *Management of motor speech disorders in children and adults* (3rd ed.). Austin, TX: Pro-Ed.

APPENDIX A: ANNOTATED BIBLIOGRAPHY

Bailey, D. J., & Dromey, C. (2015). Bidirectional interference between speech and nonspeech tasks in younger, middle-aged, and older adults. *Journal of Speech, Language and Hearing Research*, 1637-1653. doi:http://dx.doi.org/10.1044/2015_JSLHR-S-14-0083

Objectives: The objective of this study was to determine how three different nonspeech tasks would affect the motor speech performance of adults who differed in age. *Methods:* Sixty individuals participated in this study. Each individual belonged to one of three groups of twenty, either younger (20s), middle-aged (40s), or older adults (60s). All participants completed the speech task once without a concurrent nonspeech task, as well as completing all of the nonspeech tasks without a concurrent speech task. The participants then completed the speech task concurrently with each of the nonspeech tasks. The three nonspeech tasks included a manual motor task, a cognitive task, and a language task. The speech task required the participant to repeat the phrase "I saw Patrick pull a wagon packed with apples," when they heard a tone. The manual motor task required the participants to place as many pegs as possible in the Purdue Pegboard Test with both hands while repeating the target phrase over 60 seconds. The cognitive task required the participants to compare as many sets of two fractions as possible over 60 seconds and select whether they were equal or unequal while completing the speech task. The language task required the participants to decide whether two words were semantically related, categorizing as many pairs as possible over 60 seconds while completing the speech task. *Results:* The data showed significant task-specific divided attention interference. Speech and nonspeech tasks were affected by divided attention involving the linguistic and cognitive tasks. Speech tasks were affected by divided attention involving the manual motor task. The authors also note the effect that age had on the duration of the participant's utterance. *Conclusion:* Different tasks have differing effects on speech performance in divided attention situations. Speech interferes with the performance of nonspeech tasks when they are completed concurrently. The study also shows that age has an effect on speech performance during divided attention tasks. *Relevance to the current study:* The current study examines the effects of divided attention on the speech of individuals with Parkinson's disease. This study examines the effects of divided attention on the speech of sixty healthy participants spanning a wide age range.

Chen, H.-C., Schultz, A., Ashton-Miller, J., Giordani, B., Alexander, N., & Guire, K. (1996). Stepping over obstacles: Dividing attention impairs performance of old more than young adults. *The Journals of Gerontology*, M116-M122.

Objectives: The objective of this study was to determine if dividing attention during an obstacle walking task would differentially affect young adults compared to older adults. *Methods:* Thirty-two individuals were divided into four groups of eight participants. The groups consisted of young adult females, young adult males, older adult females, and older adult males. All participants were considered healthy, without any history of head trauma or other neurological impairment such as vertigo or lightheadedness. The participants were instructed to walk along an 8 m long walkway with a conductive surface while wearing shoes with two conducting strips along the sole of each. The participants' attention was divided by red, yellow, and green lights randomly presented, to which they were instructed to respond "ah" when a red light appeared. The participants completed preliminary vision tests, vocal reaction tests while standing, and walking trials. They were then instructed to complete seven control trials without any obstacles or stimulus lights, twelve trials with only obstacles presented, and sixty-nine trials with both obstacles and stimulus lights presented. *Results:* The data showed an overall slowed reaction time for all groups during walking conditions as compared to standing conditions. Older females were 29 to 54 msec slower than the young adult female group, while older males ranged from 8 msec faster to 23 msec slower as compared to the young adult male group. Both the male and female young adult groups had a higher average obstacle avoidance score than the older adult groups. Both the older and younger adult groups had a decrease in their average obstacle avoidance scores when their attention was divided, although there was a difference in performance between the two groups. The young adult group avoided the obstacles in three-fourths of the trials while the older adult group avoided the obstacles in less than one-half of the trials. The older adult group had a significantly reduced mean obstacle avoidance score as compared to the young adult group when their attention was divided and the older adult group produced two times more vocal errors than the younger adult group. *Conclusion:* This study found that although dividing the attention of the participants decreased the obstacle avoidance score for both the younger and older adult groups, the older adult group was impacted significantly more. The older adult group had increased reaction times while standing and they were less successful at avoiding obstacles, indicating age-related declines in performance as cognitive demands were increased. *Relevance to the current study:* This study examined the ability of older adults to complete multiple tasks at one time as compared to young adults while the current study examines how divided attention affects speech in older adults with Parkinson's disease. It is important to consider the natural aging effects that may contribute to the participants' performance in the current study.

Eadie, T. L. (2000). Characteristics of the aging female voice. *Journal of Speech-Language Pathology and Audiology/Revue d'Orthophonie Et d'Audiologie*, 162-179.

Objectives: The objective of this article was to address findings from recent literature regarding the characteristics of the female voice as it ages. *Methods:* Seven studies outlining differences in anatomical, physiological, perceptual, and acoustic measurements of the voice due to aging in males and females were reviewed. *Results:* The results of this review of literature indicate normal differences between male and female vocal mechanisms due to physiology and aging differences between males and females. *Conclusion:* This study found differences between male and female speakers regarding physiology and normal aging processes; however, further research measuring perceptual features of the aging female voice should be conducted. *Relevance to the current study:* The current study examines how divided attention affects the speech of individuals with Parkinson's disease as compared to healthy older and healthy young control groups. This study examined characteristics of the female voice as it ages, which provided useful information in distinguishing between normal aging effects on speech and effects related to PD in the current study.

Galletly, R., & Brauer, S. G. (2005). Does the type of concurrent task affect preferred and cued gait in people with Parkinson's disease? *The Australian Journal of Physiotherapy*, 175-180.

Objectives: The first objective was to examine how different types of concurrent tasks effect the gait of individuals with Parkinson's disease. The second was to determine if visual cues were useful in regulating the stride of individuals with Parkinson's disease, even when occupied with other concurrent tasks. *Methods:* Sixteen individuals with Parkinson's disease in Brisbane, Australia between the ages of 53 and 81 participated in the study, as well as 16 age and gender matched individuals without Parkinson's disease or any other neurological conditions. Each subject participated in one hour of testing, with the individuals with Parkinson's disease being tested while they were "on phase" of their medication cycles to ensure their most stable gait parameters. The testing included one repetition of eleven tasks, including gait only tasks and concurrent tasks. While performing the gait only task the participants walked 10 meters at an average pace. While performing the concurrent tasks the participants walked 10 meters while also speaking, performing a motor task, or performing a calculation. All concurrent tasks were also performed independently in order to gather baseline measures for each participant. *Results:* On average, the individuals with Parkinson's disease had a reduction in gait velocity of 15 meters per minute when a language or calculation task was being performed concurrently. When a motor task was performed concurrently, the average reduction in gait velocity was 5 meters per minute. The average velocity reduction for control participants was 12 meters per minute while concurrently performing a language or calculation task and 3 meters per minute while concurrently performing a motor task. Visual cues were found to have an effect on maintaining stride length, and they did not have a negative effect on the individual's gait velocity, cadence, or stride length. *Conclusion:* This study found that that the type of concurrent task had a significant impact on stride length but not on velocity or cadence. It was found that the visual cues used maintained their effectiveness, even while the individuals with Parkinson's disease were performing concurrent tasks. *Relevance to the current study:* The current study examines the effect of divided attention on several aspects of speech, while this study investigated how the different types of concurrent tasks, or divided attention, affected the gait of individuals with Parkinson's disease.

Ho, A. K., Iansek, R., & Bradshaw, J. L. (2002). The effect of a concurrent task on Parkinsonian speech. *Journal of Clinical and Experimental Neuropsychology, 24*, 36-47.

Objectives: The purpose of this study was to examine attention in speech motor control, specifically observing articulation, in individuals with Parkinson's disease. *Methods:* Fifteen participants with Parkinson's disease with hypophonic dysarthria, 11 male and 4 female, and 15 age- and gender-matched controls were selected for this study. None of the participants had a history of stroke, neurological damage, or serious head injury, with the exception of the diagnosed Parkinson's disease. Each individual participated in two different speech tasks, numerical recitation and spontaneous speech. The attention of the participants was divided by a tracking task requiring them to follow the movement of a needle. The participants were instructed to use a joystick to manipulate the needle to keep it within a targeted middle-range. The participants completed the tracking task while engaging in spontaneous speech and numerical recitation. The spontaneous speech task entailed speaking about a highly familiar subject for six minutes with a break halfway through. The numerical recitation task entailed reciting numbers in numerical order until out of breath, and then repeatedly counting from one to five until out of breath. *Results:* During the concurrent task the individuals with Parkinson's disease had reduced speech volume, reduced speech rate, increased speech pause time and initiation, and an increase in progressive volume decay compared to the control group. The individuals with Parkinson's disease and the control group performed similarly on the visuo-motor tracking task, although the volumetric and temporal measures of speech in the individuals with Parkinson's disease deteriorated when their attention was divided. *Conclusion:* The results of this study indicate that the speech of individuals with Parkinson's disease is negatively affected when attention is divided by a concurrent task. The divided attention effect on speech in individuals with Parkinson's disease indicates an inability to allocate attentional resources to both tasks, likely resulting from the frontostriatal impairment resulting from the disease. *Relevance to the current study:* This study examined the attentional resources used by individuals with Parkinson's disease during a divided attention task, specifically observing its effect on speech. The current study examines how specific parameters of speech are affected in this population during a divided attention task.

Kemper, S., Schmalzried, R., Hoffman, L., & Herman, R. (2010). Aging and the vulnerability of speech to dual task demands. *Psychology and Aging*, 949-962.

Objectives: The objective of this study was to determine the upper limits of older adults' vulnerability to dual task demands and the resulting effects on speech. *Methods:* The participants for this study included 100 young adults ranging in age from 18 to 28 years, and 97 older adults ranging in age from 65 to 85 years. All participants completed various cognitive batteries to assess age-related differences in vocabulary, processing speed, working memory, and inhibition. These batteries included vocabulary and reading tests, digits forward/backward tests, a reading span test, an operation span test, a digit symbol test, the Stroop test, and portions of the Trail Making test. Participants were also asked to complete a rotor tracking task where they were instructed to track a bulls-eye target with a computer mouse while reading a prompt aloud and then while producing a spontaneous speech sample. Prior to this testing, all participants produced a baseline language sample where their fluency, content, and grammatical complexity were assessed. *Results:* Both the young adult group and the older adult group were affected by the dual task demands during the rotor tracking performance task, but neither group was affected more than the other. Regarding the language sample task, both the young adult group and the older adult group were affected, although in notably different ways. The younger adult group produced less fluent speech with less complexity and less informative content as the dual task demands became progressively more difficult. The older adult group produced speech that was less fluent, and decreased linguistic content and grammatical complexity when presented with moderately difficult dual task demands, but when the tasks became more demanding, their abilities declined more rapidly. *Conclusion:* Overall, it was found that the older adults were more vulnerable to breakdowns in speech and language when demands became greater. Slowing down their speech did not compensate as well for the increased demands, resulting in sentence fragments, short and simple sentences lacking cohesion and lexical variety, and less informative content. *Relevance to the current study:* The current study examines the effects of divided attention on several acoustic measures of speech in individuals with Parkinson's disease. This study examines the effects of increased dual task demands on the speech and language of older adults versus younger adults, indicating a difference in the ability to compensate for the increased demand.

Kim, H. (1994). *Monotony of speech production in Parkinson's disease: Acoustic characteristics and their perceptual relations* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Full Text; ProQuest Dissertations & Theses Global. (Order No. 9508857).

Objectives: The first objective of this study was to examine the intonation patterns of sentences in patients with Parkinson's disease in order to determine how fundamental frequency, intensity, and timing contribute to the monotonous aspect of their speech. The second objective of this study was to determine others' perception of monotony in the speech of individuals with Parkinson's disease, determining whether the previously mentioned acoustic measures contribute directly to a listener's perception of monotony and whether specific acoustic measures affecting the monotony can be identified separately. *Methods:* The participants for this study included 17 adult males with Parkinson's disease and 17 age-matched males without Parkinson's disease or any other neurological deficit, ranging in age from 65 to 74 years. Eight sentence pairs including a short sentence and a long sentence were used to construct the lists used for the participants. Short sentences had five to seven syllables while long sentences had eleven to fourteen syllables. All of the sentences were recorded and four repetitions of each were created, resulting in three lists of forty sentences which were then randomized. Each participant was presented with one of the three lists and was asked to produce each sentence naturally. All of the sentences were analyzed for variation in fundamental frequency, intensity, and timing, as well as for perceptual analysis using an interval rating scale. Ten listeners rated the perceptual attributes of mono-loudness, mono-pitch, mono-duration, and severity of dysarthria. *Results:* The results showed differences in fundamental frequency, intensity, and timing between the individuals with Parkinson's disease and the control group. The individuals with Parkinson's disease had less variability of fundamental frequency, reduced intensity, and slower timing measures. The listeners rating the speech samples were unable to determine which perceptual attribute contributed the most to the monotony of speech and it was found that all four of the perceptual features were strongly correlated. Greater monotony in speech was highly correlated with a decrease in the ability to differentiate between which of the perceptual attributes being assessed contributed the most to the monotony. *Conclusion:* This study demonstrates that the characteristics contributing to monotony of speech in individuals with Parkinson's disease are highly correlated. This indicates that it may be possible to improve one of the deviant characteristics by targeting an alternate characteristic while continuing to monitor the overall prosodic behaviors and monotony of speech as a whole. *Relevance to the current study:* This study examined the interconnectedness of fundamental frequency, intensity, and timing, and how these characteristics contribute to the monotonous aspect of speech in an individual with Parkinson's disease. The current study examines how various speech patterns including frequency and intensity are affected when attention is divided in an individual with Parkinson's disease.

LaPointe, L. L., Stierwalt, J. A. G., & Maitland, C. G. (2010). Talking while walking: Cognitive loading and injurious falls in Parkinson's disease. *International Journal of Speech Language Pathology*, 455-459. doi: http://dx.doi.org/10.3109/17549507.2010.486446

Objectives: The objective of this study was to determine the effects of varying cognitive-linguistic loads on balance, gait, and ambulation in individuals with Parkinson's disease. A second objective was to determine whether the cognitive-linguistic load contributes to injurious falls in the same population. *Methods:* This study included 38 participants, 13 without neurological damage and an average age of 68.07 years, and 25 with Parkinson's disease (PD) and an average age of 67.44 years. All participants were asked to complete walking tasks while also completing tasks of differing cognitive-linguistic loads. The low linguistic load task required the participants to count by ones, the middle linguistic load task required participants to complete serial subtraction of threes, and the high linguistic load task required the participants to complete alpha-numeric sequencing. The gait parameters were analyzed using the GAITRite Portable Walkway System. *Results:* ANOVA measures revealed no significant difference between the PD group and the control group regarding stride length, although each individual participant had a reduced stride length when performing the high-load task. Similar results were found regarding velocity, with no significant difference between the two groups, but with a significant decrease in each of the individuals while performing the high-load task. A significant difference was found between the PD group and the control group when double support time was analyzed. The control group significantly increased their use of the compensatory strategy of spending more time on their left and right lower limbs, while the PD group did not have an increase, indicating they did not utilize the same compensatory strategy. *Conclusion:* This study shows that individuals with Parkinson's disease are at a greater risk for injurious falls when high cognitive-linguistic demands are placed on them while walking, indicating healthcare providers should take this into consideration when working with this population. *Relevance to the current study:* This study examines the effect of high-load cognitive-linguistic demands on the physical parameters of gait, velocity, and stride length, and how this relates to injurious falls in individuals with PD. The current study examines the effect of divided attention on acoustic measures of speech while individuals are engaged in motor tasks.

MacPherson, M. K. (2013). *Cognitive and autonomic factors in speech motor control: Effects of the aging process* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Full Text; ProQuest Dissertations & Theses Global. (Order No. 3591545).

Objectives: The objective of this study was to determine how increased cognitive load and changes in autonomic arousal affect speech in healthy young and older adults, as well as to determine if age has an impact on the relationship between autonomic, cognitive, and motor speech processes. *Methods:* Eight healthy young adults between the ages of 22 and 31 and eight healthy older adults between the ages of 68 and 78 participated in this study. Each group consisted of four males and four females and all participants reported no history of speech, language, cognitive, or neurological impairments. Each participant read congruent and incongruent Stroop condition sentences multiple times Signals were recorded in order for articulatory kinematic, perceptual, and autonomic measures to be analyzed after the fact. The acoustic signal was recorded by a microphone. Four sentences, two congruent and two incongruent, each containing 13 words and 17 syllables, were used in each block. Each sentence occurred an equal number of times during the congruent and incongruent conditions. In the congruent condition, the words were written in ink matching the meaning of the text, while in the incongruent condition, the words were written in a color different from the meaning of the text. The participants were asked to say the word for the color of ink rather than reading the text word. Each participant was presented with at least eight sets of stimuli, resulting in at least eight productions of each of the four sentences. Age group, Stroop condition, and sentence segment effects on measures of articulation accuracy and coordination were analyzed as well as autonomic arousal measurements of pulse volume, pulse period, and peak skin conductance. *Results:* The results of this study showed that an increase in cognitive load in the incongruent condition was associated with an increase in variability of articulatory coordination as well as sentence segment duration for both age groups. The increased cognitive load had a greater effect on the speech motor systems of the older adult group, resulting in greater variability of articulatory coordination and sentence segments for the incongruent condition than in the younger adult group. Both age groups had an increase in the autonomic arousal measures of peak skin conductance during the incongruent condition. The older adult group had an increase in the autonomic arousal measures of peripheral vasoconstriction and reduced pulse cycle duration during the incongruent condition as compared to the younger adult group. The older adult group also had approximately double the increase in peak skin conductance during the incongruent condition as compared to the younger adult group. Autonomic arousal had a significant impact on the speech motor performance of the older adult group, with a greater variability in articulation coordination during the incongruent condition. *Conclusion:* This study revealed that age and an increase in cognitive load have an effect on autonomic arousal and speech motor performance. This indicates that aging affects the interaction between speech, autonomic, and cognitive processes. *Relevance to the current study:* This study examines the relationship between age and increased cognitive demands and autonomic arousal on speech, while the current study examines the effect of increasing the cognitive load by dividing the attention of participants with Parkinson's disease on various measures of speech. The separate effects of age and Parkinson's disease on speech are examined.

McDowd, J. M., & Craik, F. I. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance*, 267-280.

Objectives: The first objective of this study was to evaluate how age is associated with task complexity during divided attention tasks. The second objective was to examine whether there is an exaggerated age effect in divided attention tasks as task complexity is increased. *Methods:* Sixteen young participants with an average age of 19.4 years and 16 older adults with an average age of 69 years participated in the first experiment. All participants completed a vocabulary test to screen for typical verbal ability. They performed an auditory task and a visual task at two levels of difficulty. Each of the tasks was performed singularly and then in varying combinations of dual-task conditions. Response time measurements were gathered. A group of young participants with an average age of 21 years and a group of older adults with an average age of 71.9 years for one task and 67.3 years for another task participated in the second experiment. The participants performed two visual tasks at three levels of difficulty. The two visual tasks were performed singularly and then concurrently with an auditory task. *Results:* The results of the first experiment showed that as the task difficulty increased, the reaction times increased for both the young and older age group during the single- and dual-task conditions. As the task difficulty increased during the divided attention conditions there was an increased negative impact on the older adult group compared to the younger adult group. The results of the second experiment showed an age effect on performance during the divided attention tasks as task complexity increased. It was also found that the effect of the divided attention condition during the easier task decreased as the task complexity increased. *Conclusion:* This study revealed an age effect for divided attention with older adults being affected more than younger adults, with an increased effect as the difficulty of the task increased. This study indicates that older adults may be affected during a divided attention condition only to the extent of the effect that the task complexity has on their performance. *Relevance to the current study:* This study examined how older adults are affected by divided attention tasks as compared to younger adults as task complexity increases. The current study examines the effect of divided attention on the speech of older adults with Parkinson's disease, potentially further complicating performance outcomes.

Sharpe, M. H. (1996). Is there a divided attention deficit in patients with early Parkinson's disease? *Cortex*, 747-753. doi:10.1016/S0010-9452(96)80044-X

Objectives: The objective of this study was to determine whether individuals with Parkinson's disease can equally divide their attention between two concurrent tasks as well as their neurologically healthy counterparts. *Methods:* Fourteen adults with early Parkinson's disease who had minimal motor deficits participated in this study. All of the patients were right-handed with a mean age of 61.07 years. Fourteen neurologically healthy adults also participated and were matched for intellectual status, gender, and handedness with the 14 individuals with Parkinson's. The participants listened to a monaural list of 60 words, including 10 phonemic distractors as well as 10 presentations of the target word, "dog," and a dichotic list of 132 words, including 10 phonemic distractors and 10 presentations of the same target word. The divided attention task required the participants to divide their attention between their left and right ears, listening for the target word. Each time the target word was presented it was paired with an unrelated, non-target word. The participants were instructed to press a button with their right or left hand, corresponding to the ear in which they heard the target word. *Results:* The results of this study showed that the individuals with Parkinson's disease identified the target word less often than the neurologically typical control group. *Conclusion:* This study indicates that individuals with Parkinson's disease have more difficulty dividing their attention between two simultaneously presented stimuli, suggesting that these individuals have more limitations in their overall attentional capacity. *Relevance to the current study:* This study examined the ability of individuals with Parkinson's disease to divide their attention between two simultaneously presented stimuli, determining that this population may have limited attentional capacity even during the earliest stages of the disease. The current study examines the effect of two walking tasks on several acoustic measures of speech in individuals with Parkinson's disease.

Stegemöller, E. L., Wilson, J. P., Hazamy, A., Shelley, M. C., Okun, M. S., Altmann, L. J. P., & Hass, C. J. (2014). Associations between cognitive and gait performance during single- and dual-task walking in people with Parkinson disease. *Physical Therapy*, 757-66. doi:10.2522/ptj.20130251

Objectives: The objective of this study was to examine the relationship between gait performance and cognitive performance during single and dual-task walking conditions in individuals with Parkinson's disease. *Methods:* Thirty-five individuals with mild to moderate Parkinson's disease who were independently ambulatory participated in this study. Each participant completed a cognitive assessment to determine current levels of cognitive functioning in the domains of executive function and attention, visual and verbal memory, and processing speed. Each participant also completed a gait assessment in which tasks included walking barefoot at a comfortable speed as well as walking at a comfortable speed while counting backwards by 3's. *Results:* The results showed a correlation between processing speed and gait, including stride length and gait speed. An increase in step width variability resulted in decreased attention and executive functioning. In general, the participants walked slowly in the dual-task condition, demonstrating a relationship between gait (walking speed and stride length) and cognitive processing speed. *Conclusion:* This study demonstrates that cognitive and gait performance are differentially affected during a dual-task walking condition as a result of Parkinson's disease. The slowed processing speeds indicate that the neural systems used for gait and cognitive performance overlap, affecting the performance of both tasks. *Relevance to the current study:* This study examined the effect of gait performance tasks on multiple aspects of cognition, including executive function, visual and verbal memory, and attention and processing speed, specifically examining the connection between these measures and gait performance. The results demonstrated the overlap of gait performance and the cognitive parameters of executive function and attention, visual and verbal memory, and processing speed. The current study examines the effect of dual-task gait performance on specific measures of speech.

Tjaden, K. (2008). Speech and swallowing in Parkinson's disease. *Topics in Geriatric Rehabilitation*, 115–126. doi:10.1097/01.TGR/0000318899.87690.44

Relevance to the current study: This text discusses the characteristics of dysarthria and dysphagia in individuals with PD as well as behavioral management strategies. The current study examines the speech of individuals with PD, which is often affected by dysarthria. In the current study it is important to understand the effects of hypokinetic dysarthria on speech in this population in order to differentiate it from the speech of healthy aging individuals.

Verhaeghen, P., Steitz, D.W., Sliwinski, M.J., Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging*, 443-60.

Objectives: The objective of this study was to analyze and report on a meta-analysis of 33 studies regarding aging and its effects on dual-task performance. *Methods:* Thirty-three studies were collected through personal contacts, through the PsycINFO electronic database, and by consulting the reference lists of the articles already collected. There were two requirements for a study to be included in the meta-analysis. First, the study had to have compared young adults to older adults, and second, it must have compared latency, accuracy, or both during a dual-task condition as well as during a single-task condition. In order to examine reaction time and accuracy from each of the studies, two graphical analyses were used. The first was a state-trace analysis in which performance during the dual-task and single-task conditions was plotted separately for younger and older adults. It was then determined if a single line adequately explained the data or whether two lines, one for older adults and one for younger adults, would need to be used to represent the results. A single line implied no age difference while two lines implied the need for further interpretation. The second approach was a Brinley analysis where the performance of the older adults was analyzed as a function of the performance of the younger adults. If two lines were needed to explain the relationship between the performance of the two groups, it was implied that there was an age effect during the dual-task condition. *Results:* The results for the Brinley line demonstrated a regression for both the single- and dual-task conditions, although the slope for the dual-task condition was smaller, indicating a smaller age deficit during dual-task conditions. The state-trace analysis demonstrated a larger intercept for older adults compared to younger adults, indicating additive dual-task performance costs as well as additive age effects. *Conclusion:* This study demonstrated that the performance costs during dual-task conditions are additive and that the performance costs are larger and more significant in older adults as compared to younger adults. This indicates a significant age effect on performance during dual-task conditions. In addition, it was found that performance is less accurate during dual-task conditions as compared to single-task conditions. *Relevance to the current study:* This publication examined multiple studies of age effects on dual-task performance, whereas the current study examines the effect of divided attention on the speech of individuals with Parkinson's disease. In the current study it is important to account for natural aging affects during dual-task conditions.

Yorkston, K. M., Beukelman, D.R., Strand, E.A., Hakel, M. (2010). *Management of motor speech disorders in children and adults* (3rd ed.). Austin, TX: Pro-Ed.

Relevance to the current study: This text discusses motor speech disorders, including hypokinetic dysarthria which is the most common type of dysarthria affecting individuals with Parkinson's disease. The current study examines the effects of divided attention on the speech of individuals with Parkinson's disease. In the current study it is important to understand the effects of hypokinetic dysarthria on speech in this population.

APPENDIX B: INFORMED CONSENT

You are being asked to take part in a multi-part research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends and relatives if you wish. Ask the research doctor or staff if there is anything that is not clear or if you would like more information. Take time to decide whether or not to volunteer to take part in this research study.

The purpose of the study is to collect information on how people normally navigate obstacles and changes in terrain such as climbing stairs, moving from seated to standing positions, walking on gravel, etc. so we can understand how to graphically represent this terrain in virtual environments and develop new technology and training procedures to improve stability and reduce the chance of falls.

STUDY PROCEDURES

There are 3 major parts to the study. You are being asked to agree to the parts of the study for which you are eligible, and they should be clearly marked with a checkmark (***If you do not see a checkmark next one or more parts, or are unsure which part of the consent document is applicable to you, please see one of the research staff immediately before proceeding.***).

[_____] PART 1 - DEVELOPMENT OF THE PHYSICAL ENVIRONMENT

The purpose of this part of the study is to determine and characterize aspects of your environment that you find challenging to navigate. Once we identify these activities, physical representations of these situations will be created in the Motion Analysis Core Facility (MOCAP) and Ergonomics and Safety (E & S) Laboratory for two purposes: (1) To evaluate the validity of the simulated environment of the lab and to collect movement data during these mobility challenging activities, and (2) To develop a virtual reality environment that simulates these real-world challenges.

To accomplish this, you may participate in a recorded interview with a questionnaire to define common environments and situations that cause mobility challenges for you. For example, do you trip and stumble sometimes when you walk on an uneven sidewalk? A physical environment in the laboratory will be constructed that includes the common themes identified from the interview. For participants with Parkinson disease that are already using dopamine replacement medications, all testing will be done within 1-2 hours of taking the regular dosage of dopamine replacement medications to assure medication levels are consistent.

Part one of this study will take place in two separate locations on the university campus. At both locations, you can expect the following progression of events:

- You will enter one of the motion analysis labs.
- If applicable, you will be interviewed and a questionnaire will be completed about your self-report of difficulty in various mobility challenging environments.
- Next, you will be provided with a black tight fitting shirt and shorts for testing.
- Demographic and body measurement data will be collected from you.
- Reflective markers will be placed on you.

- You will be fitted with a ceiling mounted fall harness and support system to prevent falls to the ground.
- You will be directed to stand on a special square on the floor or treadmill called a force platform.
- Next, you will be asked to complete several tasks such as walking, jumping, standing up from sitting, climbing stairs, rising up on your toes, and remaining upright when your balance is challenged. You will also be asked to engage in a recorded speech task during some of these activities.
- You will be asked to perform 5 trials of each task.
- After the tasks are complete, the markers will be removed and you can change back into your street clothes.
- Additional questions and assessments will be made using standard questionnaires to assess other factors that may be related to balance, and perceptions of difficulty during walking and interactions with your environment. For example, we will ask you to remember a list of five things and repeat them in order back to the researcher.

[______] PART 2 - SHOE DEVELOPMENT A new form of insole, or "Smart Shoe" has been created and rigorously tested in a laboratory testing fixture. Our purpose is to evaluate the changes in movement while wearing the smart shoe compared to not wearing it, and obtain feedback from you as a user to evaluate and improve smart shoe designs and identify features that provide the most benefit for providing assistance during mobility challenging activities.

Testing will include the functional gait assessment (FGA), the 6-minute walk test (6MWT), and gait analysis in a physical environment presented in the MOCAP, E&S Labs. The following is the progression of events you should expect in Part 2:

- You will enter one of the motion analysis labs.
- Next, you will be provided with a black tight fitting shirt and shorts for testing. A private changing room will be provided.
- You will be given instructions about the Smart Shoes and what to expect while wearing them.
- Demographic and body measurement data will be collected from you.
- Reflective markers will be placed on you.
- You will be fitted with a ceiling mounted fall harness and support system to prevent falls to the ground.
- You will be directed to stand on a special square on the floor called a force platform.
- Next, you will be asked to complete several tasks such as walking, jumping, standing up from sitting, climbing stairs, rising up on your toes, and remaining upright when your balance is challenged.
- You will be asked to perform 5 trials of each task.
- After the tasks are complete, the markers will be removed and you can change back into your street clothes.

- Additional questions and assessments will be made using standard questionnaires to assess other factors that may be related to balance, and perceptions of difficulty during walking and interactions with your environment. For example, we will ask you to remember a list of five things and repeat them in order back to the researcher.
- This completes this part of the study.

[______] PART 3 - VIRTUAL REALITY TRAINING
The purpose of this part of the study is to learn more about the potential benefits of training on a treadmill and virtual environment system known as the Treadport Active Wind Tunnel-Terrain Display Simulator (TPAWT-TDS). Conventional training is often limited and becomes even more complicated due to weather or being able to simulate an environment accurately in a laboratory setting. There is evidence to suggest that training activities in virtual reality may improve motor function and balance recovery after a minor perturbation. You are being asked to participate in a study to determine if the immersive virtual environment system and a Smart Shoe developed to provide realistic sensations of walking on irregular terrains in the TPAWT-TDS is more beneficial as a training device than training without VR and Smart Shoe technology. Pretesting will include the functional gait assessment (FGA), the 6-minute walk test (6MWT), gait analysis and biomechanical analysis in a physical environment presented in the MOCAP and E&S Labs. Pretesting should require approximately 2 and a half hours of your time. The following is the progression of events you should expect for pretesting:

- You will enter the MOCAP or E&S lab.
- Next, you will be provided with a black tight fitting shirt and shorts for testing.
- Demographic and body measurement data will be collected from you.
- Reflective markers will be placed on you.
- You will be fitted with a ceiling mounted fall harness and support system to prevent falls to the ground. You will be directed to stand on a special square on the floor called a force platform.
- Next, you will be asked to complete several tasks such as walking, jumping, standing up from sitting, climbing stairs, rising up on your toes, and remaining upright when your balance is challenged.
- You will be asked to perform 5 trials of each task.
- After the tasks are complete, the markers will be removed and you can change back into your street clothes.
- Additional questions and assessments will be made using standard questionnaires to assess other factors that may be related to balance, and perceptions of difficulty during walking and interactions with your environment. For example, we will ask you to remember a list of five things and repeat them in order back to the researcher.

Following pretesting, you will undergo training. Training will be performed in the TPAWT-TDS. The treatment regimen will last 6 weeks (3x/wk) for a total of 18 sessions. The duration of each session will be approximately 45 minutes with a 5-minute warm-up period of walking on the treadmill without VR or haptic display. In addition, you will be given up to 5, three-minute rest breaks, as needed. During this study your movement will be evaluated and recorded. During training you will be presented with various virtual terrains that represent mobility challenging environments. You will be tethered with a safety device during all trials. The following is the progression of events you should expect during each training regimen:

- You will enter the TPAWT-TDS.
- Next, you will be provided with a black tight fitting shirt and shorts for testing. A private changing room will be provided.
- Demographic and body measurement data will be collected from you.
- Reflective markers will be placed on you.
- Next, you will be tethered to the system with a support to prevent falls to the ground and warm up on the treadmill with the virtual environment for 5 minutes.
- Following warm up, a training session lasting 45 minutes where you will be presented with virtual terrain and a realistic virtual representation of a common setting (for example, walking on a sidewalk with uneven slabs, or walking from a room with wood flooring to a carpeted floor), during which you will experience some mobility challenging conditions.
- After the training session, the markers will be removed and you can change back into your street clothes.

Following training you will be scheduled for a final post-testing appointment at the MOCAP and E&S labs. Post-testing will include the functional gait assessment (FGA), the 6 minute walk test (6MWT), gait analysis and biomechanical analysis in a physical environment presented in the MOCAP and E&S Labs. Post-testing should require approximately two and a half hours of your time. The following is the progression of events you should expect:

- You will enter the MOCAP or E&S lab.
- Next, you will be provided with a black tight fitting shirt and shorts for testing.
- Demographic and body measurement data will be collected from you.
- Reflective markers will be placed on you.
- You will be directed to stand on a special square on the floor called a force platform.
- Next, you will be asked to complete several tasks such as walking, jumping, standing up from sitting, climbing stairs, rising up on your toes, and remaining upright when your balance is challenged.
- You will be asked to perform 5 trials of each task.
- After the tasks are complete, the markers will be removed and you can change back into your street clothes.
- This completes this part of the study.

RISKS

For this study, markers are attached to the skin with hypoallergenic tape. There may be some minor discomfort experienced when the small pieces of tape are removed from your skin. This is similar to removing very small Band-Aids. In addition, because of the need for you to perform balance activities, the risk for falling is increased. However, you will be supervised at all times by a researcher with experience in fall prevention and you will also be attached to a fall restraint tether secured to the ceiling. In the event of an unprotected fall resulting in an injury, first aid will be provided. If additional medical care is required, the appropriate emergency medical services will be provided.

RESEARCH RELATED INJURY
If you are injured from being in this study, medical care is available to you at the University of Utah Medical Center, as it is to all sick or injured people. The University of Utah has not set aside any money to pay the costs for such care. The University will work with you to address costs from injuries. Costs would be charged to you or your insurance company (if you have insurance), to the study sponsor or other third party (if applicable), to the extent those parties are responsible for paying for medical care you receive. Since this is a research study, some health insurance plans may not pay for the costs. By signing this consent form you are not giving up your right to pursue legal action against any parties involved with this research.

The University of Utah is a part of the government. If you are injured in this study, and want to sue the University or the doctors, nurses, students, or other people who work for the University, special laws may apply. The Governmental Immunity Act of Utah is a law that controls when a person needs to bring a claim against the government, and limits the amount of money a person may recover. See sections 63G -7-101 to -904 of the Utah Code.

BENEFITS
There are no direct benefits to you from your taking part in this study. We hope that the information we gain from this study will help us understand and discover effective treatments to improve balance and decrease the risk of falling for individuals with mobility challenging disorders such as Parkinson disease.

ALTERNATIVE PROCEDURES
If you do not want to take part in the study, you can choose not to participate. There are no alternate procedures offered.

CONFIDENTIALITY
We will keep all research records that identify you private to the extent allowed by law. Records about you will be kept locked in filing cabinets or on computers protected with passwords. Only those who work with this study will be allowed access to your information. Results of the study may be published; however, your name and other identifying information will be kept private. However, if we learn about actual or suspected abuse, neglect, or exploitation of a disabled or elderly person, we will report that to the proper authorities.

The nature of this study requires that we record video to evaluate activities and quantify biomechanics. These videos are used for reference and will only be used for educational reasons and at research conferences. Your name will not be used, and the face of the images will be blurred when possible, but they will never have your name associated with their images. During your movement trials, a reference video will be recorded to evaluate motion data integrity and as a quality check.

Portions of this study (part 1 only) require audio recordings for reference and evaluation. The video and audio files will only be stored until all analyses are completed for the study. Only qualified research personnel will have access to these video and audio files s and access will be controlled on encrypted, password-protected computers. Measures will be taken to prevent identifiability when possible by blurring identifying features (face), and using ID numbers instead of names on audio recordings. There may be instances in an educational or teaching environment when this is not possible.

Please indicate by initialing below that you understand that images and audio recordings of you may be used in presentations for teaching and research purposes, but all efforts will be made to prevent identifiability.

Initial _________________

PERSON TO CONTACT
If you have any questions, complaints or concerns about this study, or if you feel you have been harmed as a result of participation, you can contact and of the research staff included in the following list. If you need to contact someone for an injury that resulted from being in this study, please call Dr. Bo Foreman at 801.581.3496 or Dr. Lee Dibble at 801.581.4637 during business hours Monday through Friday. Dr. Foreman can also be reached after hours by calling 801.243.9111. If you need to speak with any of the other investigators related to this study their contact information is listed below:

- Mark Minor (PI): 801.587.7771
- Andrew Merryweather: 801.581.8118
- John Hollerbach: 801.585.6978

INSTITUTIONAL REVIEW BOARD:
Contact the Institutional Review Board (IRB) if you have questions regarding your rights as a research participant. Also, contact the IRB if you have questions, complaints or concerns which you do not feel you can discuss with the investigator. The University of Utah IRB may be reached by phone at (801) 581-3655 or by e-mail at irb@hsc.utah.edu.

RESEARCH PARTICIPANT ADVOCATE:
You may also contact the Research Participant Advocate (RPA) by phone at (801) 581-3803 or by email at participant.advocate@hsc.utah.edu.

VOLUNTARY PARTICIPATION
It is up to you to decide whether or not to take part in this study. If you decide to take part you are still free to withdraw at any time and without giving a reason. Refusal to participate or the decision to withdraw from this study will involve no penalty or loss of benefits to which you are otherwise entitled. If you don’t take part, you can still receive all standard care that is available to you. This will not affect the relationship you have with the research staff.

UNFORESEEABLE RISKS
In addition to the risks listed above, you may experience a previously unknown risk or side effect.

COSTS AND COMPENSATION TO PARTICIPANTS
You will be compensated for your time and participation in this study. You will not be charged, nor will your insurance company be charged, for any test or visit that is completed solely for the

purpose of this study. Since you will be paid for participating in this study, it is necessary for us to collect your Social Security Number. You will provide this information for a Federal W-9 Form that is filed with our Accounts Payable department. Accounts Payable will have limited access to the study information (e.g. the name of the study) for payment purposes. The amount you receive for taking part in this study will be turned into the Internal Revenue Service (IRS) as taxable income. You can choose not to provide us with your Social Security Number for this form and still participate in this study; however, we will not be able to pay you as outlined in this consent form.

NUMBER OF PARTICIPANTS

We expect to enroll a total of 80 participants at the University of Utah (40-Part 1, 10-Part 2, and 30-Part 3).

CONSENT

By signing this consent form, I confirm I have read the information in this consent form and have had the opportunity to ask questions. I will be given a signed copy of this consent form. I voluntarily agree to take part in this study.

I agree to take part in (circle parts of the study you agree to participate in):

- **Part 1**
- **Part 2**
- **Part 3**

of this research study and authorize you to use and disclose health information about me for this study, as you have explained in this document.

____

Participant's Name

__________________________ _____________

Participant's Signature Date

____

Name of Person Obtaining Consent

__________________________ _____________

Signature of Person Consent Date

APPENDIX C: NARRATIVE TRIGGERS

Personal

- Would you quit if your values did not match your employer?
- If you could be rich, famous, or influential, which would you choose and why?
- How would you define faith?
- How do you define wealth?
- Do you believe people make happiness or stumble across it?
- Which is more important, talent or hard work?
- Are you an introvert or an extrovert? What are the pros and cons of each?

Media

- Are antidrug and antismoking ads effective?
- What video game would you like to redesign?
- Do social media campaigns stimulate real change?
- Should people be allowed to obscure their identities online?
- Is TV stronger than ever or becoming obsolete?
- What ideas do you have for a reality show?
- What is your opinion about violence on television and in video games?
- What artists of today are destined for the rock and roll hall of fame?

Generations

- What is the difference between your generation and my generation and why?
- Is your generation more self-centered than earlier generations?
- Are young people generally more selfish than their parents and grandparents?
- How will our current culture be remembered in history books?
- Do children today have good manners?
- Does age make you more aware of and caring for others?
- Should adults try to teach young people lessons or should they leave them alone to find out about things themselves?
- Should parents continue to financially support their children after the children are 18?
- Is modern culture ruining childhood?

Local Issues

- If you could expand the Trax system, what changes would you make?
- What do you see as the pros and cons of the proposed rebuilding of the Salt Lake airport?
- Is it important to shop at locally owned businesses?
- What could be done about Salt Lake’s homeless population?

- What are the pros and cons of the Sugarhouse trolley?

Social

- What has caused the obesity epidemic in America?
- Should people get plastic surgery?
- Should rich people have to pay more taxes?
- What is your opinion about cloning?
- What are the ethical implications of eating meat?
- Are children of illegal immigrants entitled to a public education?
- Should welfare recipients be required to take drug tests?
- If you were a philanthropist, what groups would you finance and why?
- When should juvenile offenders receive life sentences?
- Should women soldiers be in combat?
- What is your opinion about legalizing marijuana?
- Are we losing the art of listening?
- Do attractive people have advantages that others don't?
- What are the most important changes in the world since the year 2000?

Education & Related

- Is online learning as good as face-to-face learning?
- How necessary is a college education?
- Should cash-strapped schools cut arts education?
- Should guns be permitted on college campuses?
- What do you think about home school vs. public vs. private school?
- How would you make over the university system?
- Whose fault is it if a child is failing in school?
- Should parents/grandparents give cash rewards to kids for good test scores?
- Should university students be required to take drug tests?
- Should junk foods and soda pop be sold in elementary school or high school vending machines?
- How well do you think standardized tests measure people's abilities?