April 2020

Acoustic Changes during Passage Reading in Speakers with Parkinson's Disease

Kimberly C. Grubbs
Louisiana State University at Baton Rouge

ACOUSTIC CHANGES DURING PASSAGE READING IN SPEAKERS WITH PARKINSON'S DISEASE

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Arts

in

The Department of Communication Sciences and Disorders

by
Kimberly Clarissa Grubbs
B.A., The University of Southern Mississippi, 2018
May 2020

ACKNOWLEDGMENTS

I would first like to thank God for guiding me through this process. There were many times I wanted to give up, but God's mercy continually allowed me to find the words to say.

Secondly, I would like to thank my mother who looks down on me from heaven and has watched over me during this process. May she rest in peace.

I would like to thank my sisters, Nicole and Dakayla, for supporting me through the process. I would also thank my boyfriend Adrian, for supporting me through my highs and lows. To my best friends Sara, Jessica, and Breneesha, thanks for the long motivational conversations; they will live in my heart.

I would also like to thank the LSU Motor Speech Lab members who were involved in the bulk of this research project: Austin Thompson, Alexis Espinal, and Ashlyn Lee. Without their assistance, I would not have been able to complete this thesis project.

I would also like to acknowledge Dr. Donovan and Dr. Chung for serving as my thesis committee members. Thank you for embarking with me on this journey.

Lastly, I would like to thank my thesis advisor Dr. Yunjung Kim. I appreciate all of the guidance that Dr. Kim has given me during this journey. I thank Dr. Kim for the opportunity to work in her research lab; it is truly an honor. I do not take this opportunity for granted.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Purpose: The purpose of this study was to evaluate speech changes in Parkinson's disease (PD) while reading a passage, using both local (i.e., segment level) and global (i.e., utterance level) acoustic measures.

Methods: 20 speakers participated in the study (10 PD, 10 neurologically healthy controls). The speakers were asked to read *The Caterpillar* passage in a conversational mode. A total of five acoustic measures were included (local: vowel duration, Euclidean distance between corner vowels and schwa; global: articulation rate, F0/intensity range). These acoustic measures were compared between two sentences located in the two positions within the paragraph, initial and final.

Results: The findings indicated (1) overall speech differences between the two groups such as increased vowel duration and reduced vowel contrast and (2) speech differences between the beginning and end of the passage such as increased articulation rate toward the end. In addition, the results revealed that unlike control speakers, speakers with PD did not show a greater F0 and intensity range in the end compared to the beginning of the passage, which points a limited capability of prosody modulations in PD and its apparent pattern toward the end of passage reading.

Discussion: Findings of this study support the notion that within- or across-task acoustic variation should be considered in speech sampling in clinical practice and research.

CHAPTER 1. INTRODUCTION

Parkinson's disease (PD) is a neurological disease characterized by loss of dopaminergic (DA) neurons in the substantia nigra pars compacta (SNpc) and the formation of Lewy bodies, intracellular aggregates composed of misfolded α-synuclein (Goedert, 2015). The neurophysiological changes result in the key motor (hypokinesia, resting tremor, rigidity, bradykinesia) and non-motor (cognitive impairment, sleep and/or mood disorders, gastrointestinal disturbances) signs of PD. Dysarthria is frequently associated with PD. As hypokinesia (reduction in body movement) reflects the central neuro-pathophysiology of PD, hypokinetic dysarthria has been known as the dysarthria of PD (Duffy, 2013).

Hypokinetic dysarthria is known to exhibit speech characteristics such as monopitch, monoloudness, breathy voice, reduced stress, and imprecise consonants (Darley, Aronson, & Brown, 1969). Among many, one distinctive characteristic of hypokinetic dysarthria is festinating speech. As first described in gait and in handwriting, speech tends to accelerate in people with PD which likely results in the perceptual impression such as variable rate, short rushes of speech, increase of rate in segments, increase of rate overall (Darley, Aronson, & Brown, 1969). The current study aims to examine changes in speech deficits of PD within a passage reading task using acoustic analyses whether deterioration of speech in PD over passage reading is greater compared to neurologically-healthy speakers. This is an important methodological issue for researchers and clinicians regarding speech sampling for evaluation.

CHAPTER 2. REVIEW OF LITERATURE

Parkinson's Disease (PD)

Parkinson's disease (PD) is a neurodegenerative disease of the central nervous system caused by a loss of the neurotransmitter dopamine which affects the basal nuclei and substantia nigra. Dopamine is important for regulating movements, but when dopamine is reduced in PD there will be cell death in the substantia nigra resulting in motor and non-motor deficits (Weismer, 2007; Schapira, Chaudhuri, & Jenner, 2017).

Motor deficits resulting from PD include rigidity, tremor, and bradykinesia, which are considered landmark features of the disease. Erro and Stamelou (2017) state that bradykinesia is the slowness of movement and progressive reduction of either frequency or amplitude of repetitive movements (Erro & Stamelou, 2017; Postuma et al., 2015). Due to these motor deficits, up to 90% of PD patients experience voice, speech, and swallowing disorders and 80% this population suffers from reduced intelligibility; all important functions needed to maintain a healthy quality of life (Duffy, 2013; Ho et al., 1998; Logemann et al., 1978). Overall, these motor features are important in determining PD severity and will need to be discussed in detail to provide a sound insight of deficits and communication impairments which may arise.

PD may also cause non-motor features which may disrupt the patient's quality of life. These non-motor features may include mood and sleep disorders, sensory disorders (including reduced/loss of olfaction), and/or gut disorders (Scheperjans et al., 2015; Parashar & Udayabanu, 2017).

Speech Problems in PD

PD may affect one's communication abilities creating mild to severe communication impairments. Miller et al. (2007) states that a communication impairment may be present in up to 90% of Parkinson's patients. The onset of these communication difficulties may be present during early or later stages of one's diagnosis (Miller, 2007). These deficits may have negative effects on one's ability to communicate with others such as intelligibility deficits, which negatively affects the quality of life to a greater degree than other dysarthria symptoms such as poor voice quality (Karnell et al., 1999).

Frequently, individuals with PD present with hypokinetic dysarthria, known as the dysarthria of PD (Duffy, 2013). Consistent with other types of dysarthria, hypokinetic dysarthria can result in speech disturbances in any of the following categories: respiration, phonation, articulation, and prosody. Acoustic and articulatory studies on speech characteristics of PD have progressed in a way to support and explain perceptual impressions (Darley, Aronson, & Brown, 1969). The following sections summarize speech characteristics of PD reported by (1) auditory-perceptual, (2) acoustic, and (3) articulatory kinematic studies.

Auditory Perceptual Approach. Auditory-perceptual studies mostly stem from the findings and framework of the dysarthria classification system (as known as the Mayo Clinic classification) suggested by Darley, Aronson, and Brown (1969a, 1969b), which has been considered the gold standard for differential diagnosis of speakers with dysarthria (Bunton et al., 2007). The Mayo Clinic classification includes 38 auditory-perceptual features related to voice, respiration, resonance, articulation, and prosody, based on which five pure types of dysarthria are categorized: flaccid, spastic, ataxic, hypokinetic, and hyperkinetic. The literature including

Darley, Aronson, and Brown (1969) has reported speech characteristics of hypokinetic dysarthria as follows, all of which contribute to speech intelligibility deficits in PD.

Respiratory characteristics of hypokinetic dysarthria include decreased loudness, short phrases of speech, and hurried speech generation as a result of inadequate breath support. Additionally, this inadequate breath support results in a reduced ability to sustain prolonged phonation, reduced exhalation of speech production, and breathy or hoarse voice quality.

Phonatory qualities of hypokinetic dysarthria are described as hoarse or breathy voice (Grewell, 1957). Additional phonatory characteristics include monotone voice, reduced or low pitch, reduced loudness, and inappropriate silences of speech (Grewel, 1957; Hammen & Yorkston, 1996). Lastly, Duffy (1995) stated that dysphonia may be the most debilitating speech feature of speakers with hypokinetic dysarthria. Duffy (2013) stated that reduced range of motion may be the most significant underlying neuromuscular deficit in hypokinesia as it affects speech.

One with hypokinetic dysarthria secondary to PD may present with *articulatory* characteristics such as imprecise productions of affricates, fricatives, and velar stops (Duffy, 1995). For example, Duffy (1995) stated that velar stops can be perceived as fricatives due to incomplete articulatory contact and continual production of air during a stop period. Logeman and Fisher (1981) also argued that specific perceptual features of imprecise consonants characterize speech deficits in PD, which include a predominance of errors occurring for stop-plosives. Additionally, Duffy (1995) and Weismer (1984) discussed a unique characteristic of hypokinetic dysarthria, spirantization, which is the replacement of a stop gap with low intensity frication due to incomplete articulatory closure. This may be the result of articulatory undershoot caused by both accelerated rate and/or reduced range of movement.

Lastly, *prosodic* disturbances are another well-studied speech problem in PD (Darley, Aronson, & Brown, 1969). This includes monopitch, monoloudness, reduced stress, variable speech rate, and short rushes of speech. An important, distinctive feature of hypokinetic dysarthria is festinating speech, which is the acceleration of speech especially at the end of a sentence or part of a sentence, also resulting in unintelligible speech. Many speech characteristics are very likely affected by this festinating pattern, given the important role of speech rate in speech parameters (Lindblom, 1963).

Despite the frequent use of auditory-perceptual evaluations in clinic, several studies have argued that few lack consistent measures of rater reliability. Many studies (Bunton & Kent, 1996; Zyski & Weisiger, 1987) have focused on interrater reliability, but many are lacking measures of intrarater reliability. This is an important issue to consider if this option serves as the "gold standard" of dysarthria classification; there is a need for consistent rating measures to provide consistent and reliable measures to serve as a tool used in clinical settings (Bunton et al., 2007).

Zyski and Weisiger (1975) determined interrater reliability by providing graduate students and experienced professionals with audio samples of My Grandfather (Gray, 1936). These two groups were asked to listen and rate dysarthria speech impairment severity on a 7-point scale. To add, Zeplin and Kent (1996) investigated five judges' inter- and intra-rater reliability of speakers with dysarthria with two tasks: repetition of syllables and passage reading. Zeplin and Kent's 1996 study provided insight that intra-rater reliability was good, but the interrater degree of each rating was not consistent between listeners. With these results, one can concur that intrarater reliability plays a large part in establishing consistent clinical standards to classify speakers with dysarthria. These two studies show that the reliability of auditory-perceptual studies of The Mayo-Clinic features is not sufficient enough to accurately classify speakers with dysarthria.

Lastly, Bunton et al. (2007) challenged these previous studies' interrater reliability results by providing two listener groups with speech samples of 47 speakers with dysarthria. Listenrs rated the 38 perceptual Mayo Clinic features by using a 7- point scale (Bunton et al., 2007). The first of the two listener groups contained unexperienced clinicians and the second group contained clinicians with over 7 years of clinical experience. Results of this study showed consistency between raters but established that this measure may not be the gold standard for clinical practice.

Owing to advance in speech technology, acoustic and articulatory kinematic studies in dysarthria have progressed in a way to support and explain perceptual impressions to compensate the drawbacks of auditory-perceptual studies by providing objective, quantitative data.

Acoustic Approach. Many acoustic measures have been examined in speakers with PD. Among them, the current review will focus on several acoustic measures that have been preferred by the literature to characterize speech produced by PD: second formant frequency (F2) slope, acoustic vowel space area (VSA), vowel duration, and voice onset time (VOT).

Several studies have examined second formant frequency (F2) trajectories of PD speakers with dysarthria and commonly reported reduced F2 slope in speakers with PD (Kim et al., 2009; Lam & Tjaden, 2015; Feenaughty, Tjaden, & Sussman, 2014). For example, Kim et al. (2009) compared F2 slopes in various words (e.g., wax, hail, row, coat) between speakers with PD and stroke and concluded that reduced F2 slope may be a critical cause of speech intelligibility deficits for both speaker groups. Additionally, the authors suggested that it is critical to select appropriate speech stimuli and tasks for investigating acoustic characteristics of dysarthria.

Additional studies have focused on other acoustic features including, acoustic vowel space area (VSA), short vowel duration, and abnormal voice onset time (VOT).

Vowel space area has been used in multiple studies to evaluate vowel articulation (Whitehead, 2019; Whitfield & Mehta, 2019; Bradlow, Torretta, & Pisoni, 1996; Picheny, Durlach, & Braida, 1985; Tjaden et al., 2013; Turner, Tjaden, & Weismer, 1995; Whitfield & Goberman, 2017). To calculate, the first formant and the second formant frequency coordinates are typically obtained from the midpoint of four corner vowels, /i/,/u/,/a/, and /ae/ and are frequently used to construct the vowel quadrilateral and calculate vowel space area (Whitfield & Mehta, 2019; Tjaden et al., 2013; Turner et al, 1995; Whitfield & Goberman, 2017; Yunusova, Weismer, Westbury, & Lindstrom, 2008). Vowel space has been used to examine within-participant articulatory changes that associated with changes of vocal loudness (Whitfield & Mehta, 2019; Tjaden et al., 2013; Tjaden & Wilding, 2004; Whitfield, Dromey, & Palmer, 2018). Prior reports suggest that speakers with PD obtain considerably smaller vowel space area than controls (Whitfield & Mehta, 2019; Hsu et al., 2017; Tjaden et al., 2013; Whitfield & Goberman, 2014). However, there are other studies that have reported group differences in vowel space area that do not have significant findings (Whitfield & Mehta, 2019, McRae et al., 2002; Rusz et al., 2011; Sapir et al., 2007, 2010; Weismer et al., 2001).

Short vowel duration is another speech feature that has been evaluated by acoustic studies of speakers with PD. Tjaden et al.'s 2013 study focused on vowel acoustics of speakers with PD and Multiple Sclerosis to evaluate three different speaking conditions: clear, loud, and slow. This study evaluated the impact of increased vocal intensity, articulation rate reduction, and speaking conditions on vowel productions of speakers with Multiple Sclerosis and PD (Tjaden et al., 2013). Tjaden et al.'s 2013 study showed that vowel durations in the slow condition were maximized for healthy controls, but there was limited lengthening for MS and PD speakers to produce less centralized vocal tract configurations.

Lastly, several studies have evaluated voice onset time (VOT) of speakers with PD (Forrest, Weismer, & Turner, 1989; Bunton & Weismer, 2002; Flint et al, 1992; Fischer & Goberman, 2010; Harel et al., 2004). VOT is the time period between initial articulatory release of a stop consonant and the onset of voicing for the following vowel (Kent & Read, 2002). There are a multitude of studies that focus on VOT, and the results have been varied to show significance on populations with PD. Flint et al. (1992) found that VOT duration was shorter in speakers with PD as compared to healthy controls. Fischer and Goberman (2010) stated that the inconsistent findings for individuals with PD may be due to the lack of examination independent of speech rate. Fischer and Goberman's (2010) study found that PD speakers presented with articulatory undershoot and this warranted no difference in VOT of PD speakers as compared to healthy controls. Harel et al. (2004) reported that VOT times for PD speakers increased with introduction to drug therapy in comparison to pretreatment levels, and this may indicate that VOT is affected later in course of PD than fundamental frequency variability.

Articulatory Kinematic Approaches. In addition to earlier studies that have heavily relied on auditory-perceptual and acoustic analyses, owing to the advancement in speech science, a growing number of studies have directly reported labial and lingual movement characteristics in PD to evaluate a suggested orofacial muscle hypokinesia in speakers with PD which may be similar to limb bradykinesia (Darley, Aronson, & Brown, 1975).

Some electromyographic studies have been used to evaluate orofacial muscle rigidity which may result in an articulatory undershoot when speech is produced. These electromyographic studies look at movement disorders secondary to dysarthria to aid in determining articulatory deficits in speakers with PD. Wong et al. (2010) evaluated lingual kinematics of PD speakers during a speech task using electromagnetic articulography and discovered that individuals with PD presented with impaired lingual control. Additionally, this study suggested that increased range of articulatory movement in the release phase may be the reason for imprecise articulation in PD speakers (Wong et al., 2010).

Wong (2014) used electromyographic articulography to evaluate lingual and labial kinematics in Cantonese PD speakers with dysarthria. This study revealed that speakers showed reduced velocity in lingual movements and reduced distance traveled and velocity in labial movements (Wong, 2014). Additional studies have revealed reduced movement size in lower lip and jaw movements of speakers with PD (Ackerman et al., 1997; Connor et al., 1989; Forrest & Weismer, 1995; Forrest, Weismer, & Turner, 1989; Hirose, Kiritani, Ushijima, Yoshioka, & Sawashima, 1981). Other studies have reported that articulatory movements are not as distinct and occupied more space of the vocal tract than speakers without dysarthria due to PD (Kent & Netsell, 1978; Kent, Netsell, & Bauer, 1975).

In addition to reduced movement size in the articulators, speech rate of speakers with dysarthria have also been evaluated in articulatory kinematic studies. Other studies have reported specific findings in regard to articulatory slowness (Weismer, 1991) and perceptual features (Darley, Aronson & Brown, 1969a, 1969b). Studies have reported PD speakers to have slower lip and jaw speeds than healthy controls (Caliguiri, 1987; Connor, Abbs, Cole, & Gracco, 1989; Forrest & Weismer, 1995; Forrest, Weismer, & Turner, 1989).

Lastly, increased durations of speech have been evaluated and may be due to slowness of the articulators. Studies have evaluated short closing of vowel-consonant (VC) movement durations of PD speakers with dysarthria and may have resulted from reduced amplitude (Forrest

& Weismer, 1995). Yunusova, Weismer, Westbury, and Lindstrom (2008) used articulatory kinematic studies to evaluate movement measures and articulatory profiles of ALS and PD speakers with dysarthria. Findings of this study revealed that ALS and PD speakers with dysarthria did not present with significant findings as compared to healthy controls for vowel related movement. On the other hand, results for movement characteristics of PD and ALS speakers varied revealing longer lip movement durations in both populations (Yunusova, Weismer, Westbury, & Lindstrom, 2008). Lastly, a word and vowel effect were reported stating that there was a variety of effects for movements and speeds of movements due to presence of dysarthria.

Speech Tasks Used for Studying PD Speech

Various speech stimuli and tasks have been used to study speech characteristics of PD including vowel prolongation, syllable repetition, word repetitions, sentence recitations, and passage reading. For example, Rosen, Kent, and Duffy (2005) evaluated intensity of phonation decay in speakers with PD by comparing specific speech tasks including vowel prolongation, syllable repetition (diadochokinesis or DDK, puh-tuh-kuh), isolated sentences (e.g., “The boiling tornado cloud moved swiftly”), and conversational speech samples. One of the main findings of this study was significant effects of speech tasks on speech deficits in PD. Based on the findings, the authors highlighted that at least some acoustic features such as intensity slope show task-specificity between PD and healthy speakers.

Other studies also have noted that quasi-speech tasks, isolated words, or read text does not necessarily predict patterns in conversational speech such as (Kent, Kent, Rosenbek, Vorperian, & Weismer, 1997; Liberman, Katz, Jongman, Zimmerman, & Miller, 1985; Tjaden & Watling, 2003; Yaruss & Logan, 2002). For example, previous kinematic studies that use sentences such as “buy bobby a puppy (Dromey, 2000)” have showed little ecological validity due to their lack of naturalness. There has been an increased need of tasks which evaluate natural conversational speech, and passage reading has served as an important task to identify deficits due to festinating speech and speech deterioration. Although conversational speech is ideal to examine speech characteristics in any population given its naturalness, it is very variable and lacks consistency. Therefore, a large sample size is needed to show large changes (Rosen, Kent, Delaney, & Duffy, 2006). Partly because of this, passage reading has been widely used in dysarthria research as it is considered to better approximate the requirements for spontaneous speech (Duffy, 2013; Patel et al., 2013).

Passage reading is a linguistic task that evaluates acoustic variables of those with healthy and disordered speech patterns. Early research focused tasks that were not natural such as allowing participants to complete alternating motion rates (AMRs) and calculating diadochokinetic rate. There has been a need for tasks that resemble conversational speech. Certain conversational speech tasks, such as passage reading, may be valuable in determining one’s dysarthria severity especially for one with PD. Various passages have been used in dysarthria research including “The Grandfather Passage” (Darley, Aronson, & Brown, 1969a, 1969b; Reilly & Fisher, 2012), the “Rainbow Passage” (Fairbanks, 1960), “The Farm script,” (Crystal & House, 1982), the “Hunter script,” (Crystal & House, 1982), “The John Passage,” (Tjaden & Wilding, 2004), and “The Caterpillar” (Patel et al., 2013). Patel et al. (2013) designed *The Caterpillar* passage for the purpose of assessment of motor speech disorders in which linguistic and prosodic aspects of speech can be considered within a controlled context. To date, two studies have directly investigated speech changes within a passage reading task. Skodda and Schlegel (2008) focused on speech timing and pause variables at the beginning and end of a

German passage read by 121 PD speakers and 70 healthy controls. Results indicated that there is an increase in speech rate at the end of the passage for both groups, but PD speakers' speech rate increased more relative to healthy controls.

Another study, Kuo and Tjaden (2016), needs a detailed description as this study motivated the current study. Kuo and Tjaden (2016) evaluated acoustic variation patterns in 14 healthy controls and 27 speakers (15 Multiple Sclerosis and 12 PD) with dysarthria. This study identified specific acoustic features such as global speech timing, vocal intensity, sound pressure level, and segmental articulation while the two groups read the John Passage (Tjaden and Wilding, 2004). The authors compared the selected acoustic measures across three positions of the passage (beginning, middle, and ending) by using habitual and nonhabitual speaking conditions (slow and loud). Selected acoustic measures included runs per segment, run duration, articulation rate, speech rate, total pause count, pause duration, percentage of grammar pauses, mean SPL, mean SPL SD, and F2 interquartile range (IQR). The results suggested in general no significant interaction (position x speaker group) on the selected acoustic measures. For example, trends of articulation rate increased toward the end of the passage, and F2 IQR decreased toward the end of passage for all speaker groups, consistent with Skodda in Schlegel (2008). Based on the findings, the authors highlighted that speakers with dysarthria share similarities in within-task acoustic variations during passage reading with healthy speakers and that within-task acoustic variation measures during passage reading should be considered when selecting speech samples for clinical practice and research. In addition, the authors speculated that level of patient speech impairment severity contributed to this aforementioned result, because the majority of the participants presented with mild to moderate dysarthria severity.

Purpose

The purpose of this study was to expand the findings of Kuo and Tjaden (2016) by employing both local (i.e., segmental) and global (i.e., prosodic) acoustic measures and including dysarthria speakers with a wide range of severity which is indexed by speech intelligibility scores. This is based on what Kuo and Tjaden (2016) mostly focused on global measures; one segment-related measure, F2 IQR was also obtained from the utterance level. In particular, to examine vowel distinctiveness in speakers with PD, the current study employed a speaker-oriented approach in consideration of large interspeaker variability. That is, schwa was used as a reference point for each speaker and the distance between schwa and each corner vowel was computed. The use of schwa-referenced vowel contrast in the studies of PD speech has been supported (Kuo, 2017).

Research Questions

To this aim, the following three research questions were posed:

1. Do speakers with PD show significant group differences as compared to healthy controls? (Speaker Group Effect)
2. Do the selected measures differ between initial and final passage position between healthy speakers and speakers with PD? (Passage Position Effect)
3. Is there an interaction between PD and healthy control speaker groups and passage positions for the selected measures? (Speaker Group x Passage Position)

Hypothesis

1. Based on prior work, it was hypothesized that PD speakers show significant group differences as compared to healthy controls such as reduced vowel space and F0/intensity variation.
2. Based on prior work, it was hypothesized that both speaker groups show declines in the selected measures due to general speaking fatigue for the two speaker groups and festination speech for the PD group (Solomon, 2000).
3. Based on prior work, it was hypothesized that speakers with PD show declines in the selected measures to a greater degree compared to the healthy control group.

CHAPTER 3. METHODS

Participants and Task

The current study used an existing database that was established for a larger project. 20 participants (10 PD, 10 neurologically healthy controls) were selected from the database based on the gender, age, and severity of PD. This study was created and submitted to the IRB Board at Louisiana State University due to use of human subjects. After IRB approval, participants in this study were recruited from a university setting, clinics, and conferences within the state of Louisiana. Participants met two criteria: (1) neurologically-healthy speaker or (2) medical diagnosis of PD. Additionally, participants were between the ages 20 and 85. Two participants (n=1 HC and n=1 PD) were female and the other 18 participants (n=9 PD and n=9 HC) were male. Participants' age ranged from 20 years to 85 years of age. Participants' median age was 33.4 with a range of 67.5 years. All participants demonstrated and self-reported the cognitive abilities to participate in this study. Speech severity of the participants with PD was judged ranging from mild to severe by a graduate student within the Communication Sciences and Disorders program.

Table 1. Participant Demographic Information

Participant	Group	Gender	Speech Severity	Age (in years)
S 11	PD	Male	Severe	63
S 12	PD	Male	Moderate Severe	77
S 17	PD	Female	Mild	73
S 18	PD	Male	Moderate Severe	71
S 22	PD	Male	Mild	67
S 23	PD	Male	Mild Moderate	49
S 24	PD	Male	Mild Moderate	67
S 25	PD	Male	Severe	68
S 26	PD	Male	Mild Moderate	60
S 28	PD	Male	Severe	80
S 2	HC	Male	Not available	20
S 10	HC	Female	Not available	23
S 14	HC	Male	Not available	22
S 16	HC	Male	Not available	55
S 19	HC	Male	Not available	28
S 27	HC	Male	Not available	40
S 30	HC	Male	Not available	49
S 31	HC	Male	Not available	21
S 32	HC	Male	Not available	51
S 33	HC	Male	Not available	25
S 34	HC	Male	Not available	85

Note: Mean age 33.4 years with a range of 67.5 years

As part of the study protocol, the participants were asked to read *The Caterpillar* passage in a conversational voice. *The Caterpillar* was selected because it is phonetically balanced and representative of everyday speech and allows clinicians to control the context of the passage.

Acoustic and kinematic data were simultaneously collected using a 3D electromagnetic articulography system (WAVE, Northern Digital Inc, n.d.). However, the current study reported only acoustic data. To minimize the potential effect of sensors on speech production, at least 10 minutes of the adaptation period was provided to all participants prior to recording experimental utterances (Dromey & Hunter, 2016).

Acoustic data were obtained in a sound-attenuating booth with a sampling rate of 20 kHz and 16-bit quantization. A microphone (AKG C1000S) was positioned approximately 30 cm from the speaker's mouth.

Data Analysis

Four comparable sentences in terms of length from *The Caterpillar* (Patel et al., 2013) were used for the current analysis: two sentences from the beginning and two from the end. The sentences from the beginning include 27 words and 42 syllables ("To amuse myself, I went twice last spring. My most memorable moment was riding on the Caterpillar, which is a gigantic roller coaster high above the ground"), while the sentences from the end include 29 words and 44 syllables ("That night I dreamt of the wild ride on the Caterpillar. Taking a trip to the amusement park and riding on the Caterpillar was my MOST memorable moment ever!").

As previously addressed, acoustic measurements were made using the local (i.e., segmental level) and global (i.e., utterance level) variables. TF32 software was used for acoustic analysis (Milenkovic, 2005). When necessary, manual correction was made to raw F2 trajectories and F0 contours prior to measurements. Table 1 summarizes selected acoustic measures, which is followed by detailed descriptions of each measure.

Table 2. Summary of Selected Acoustic Measures

Level	Acoustic Measures
Local	• Euclidean distance between corner vowels and /ə/ on F1-F2 planes measured at the temporal midpoint of each vowel (Hz) • Vowel Duration (ms)
Global	• Articulation rate (syl/s) • F0 variation (Max-Min of F0 within utterances) • Intensity variation (Max-Min of intensity within utterances)

F0: Fundamental frequency, F1: First formant frequency, F2: Second formant frequency

Local Measures. Local measures focused on vowels, given the importance of vowel acoustics in speech characteristics of PD (e.g., Kim, Kent, & Weismer, 2011). The measures included vowel duration and Euclidean distance between corner vowels and schwa. Words with similar phonetic contexts from passage beginning and passage ending positions were selected for analysis (Table 2).

Vowel duration was measured as the time difference between the onset and offset of each vowel, which were identified by examining both the waveform and spectrogram displays. The Euclidean distance was computed for vowel pairs (corner vowels and schwa) on F1-F2 planes. F1 and F2 values were obtained from the temporal midpoint of each vowel. Table 2 provides individual vowels (words), which were included in computation of the Euclidean distance.

Table 3. Selected Target Sounds and Words for Local Measures

	Front		Back
High	/ɪ/: (Caterpillar) /ɛ/: (memorable)		/ju/: (amuse, amusement) /u/: (to) /oʊ/: (most) and (moment)
		/ʌ/: (was) /ə/: (the)	
Low	/æ/: (Caterpillar)		/ɑ/: (parks) and (on)

Global Measures. Global measures included three measures: articulation rate, fundamental frequency (F0) range, and intensity range. Articulation rate was calculated as the number of syllables (syl/s) per utterance. F0 and intensity range was computed as the difference between the maximum and minimum values within each utterance in Hz and dB, respectively.

Statistical Analysis. To examine the two main effects (Speaker Group and Passage Position) and one interaction (Speaker Group X Passage Position), a Two-Way Multivariate Analysis of Variance (MANOVA) was employed using R Studio software. A Two Way MANOVA was utilized to evaluate the independent, fixed factors (speaker group) and dependent variables (local/global acoustic measures and passage position) to determine the significance for each hypothesis. The Two Way MANOVA was utilized to determine if there were linear relationships between each dependent variable and covariate pair. Each acoustic variable was submitted to the analysis and the significance level was set at .05. If the *p* value was less than .05, the findings were considered to be highly significant.

Reliability of Acoustic Measurements

To establish inter-measurer reliability, data from two speakers (i.e., 10% of the data) were randomly selected and measured by a second lab member. Pearson's correlation coefficient was used to assess the reliability between the two lab members' measures. The correlation coefficient between the measurers indicated high inter-measurer reliability, r (148) = .971, p<.001.

Similarly, to establish intra-measurer reliability, 10% of the data was randomly selected to be remeasured by the original measurer approximately one month after the initial measurement. The correlation coefficient between the initial and remeasurement indicated high intra-measurer reliability, r (148) =.995, p <.001.

CHAPTER 4. RESULTS

The results of the study addressed the three research questions: (1) do speakers with PD show significant differences compared to healthy controls (group effect); (2) do the selected measures differ between initial and final passage position between healthy speakers and speakers with PD (position effect); and (3) is there an interaction between PD and healthy control speaker groups and passage positions for the selected measures (group x position interaction)? Findings are reported in the following per each research question.

Speaker Group Effects on Acoustic Measures

Table 3 summarizes the group effects from the two-way MANOVA for the selected local and global measures. For local measures, speakers with PD demonstrated significantly longer vowel durations compared to the healthy speakers, $F\ (1,123) = 33.796$, $p < .001$. Additionally, speakers with PD produced smaller Euclidean distances between vowels and schwa compared to the healthy speakers, $F\ (1,123) = 4.707$, p=.032. For global measures, none of the acoustic measures were sensitive to group differences.

Table 4. Summary of Statistical Results of Speaker Group Effects

Measure		HC M (SD)	PD M (SD)	$F*$	p	η_p^2
Local	Duration (ms)	94.15 (25.49)	118.17 (38.73)	33.796	<.001	0.216
	Vowel - /ə/ acoED (Hz)	0.35 (0.25)	0.30 (0.21)	4.707	0.032	0.037
Global	Articulation Rate (syl/s)	5.53 (0.72)	5.21 (1.13)	0.720	$n.s.$	
	F0 Range (Hz)	133.30 (69.51)	104.86 (52.66)	1.201	$n.s.$	
	Intensity Range (dB)	29.52 (3.46)	27.31 (3.25)	3.030	$n.s.$	

HC = Healthy Controls, PD = Parkinson's Disease, M = mean, SD =standard deviation, acoED = Acoustic Euclidean distance between the vowel and /ə/, F0 = fundamental frequency, n. s. = not significant

* $F(1,18)$ for global measures, and $F(1,123)$ for local measures.

Passage Position Effects on Acoustic Measures

Table 4 summarizes the passage position effects from the two-way MANOVA for the selected local and global measures. Of all the measures, only articulation rate was significantly affected by passage position, with both speaking groups increasing their articulation rate at the end of the passage, *F* (1, 18) = 15.162, *p* = .001.

Table 5. Summary of Statistical Results of Position Effects

Measure		*Passage-Initial M (SD)*	*Passage-Final M (SD)*	$F*$	p	η_p^2
Local	Duration (ms)	106.27 (36.11)	106.67 (33.60)	0.029	$n.s.$	
	Vowel - /ə/ acoED (Hz)	0.33 (0.24)	0.31 (0.23)	1.037	$n.s.$	
Global	Articulation Rate (syl/s)	5.09 (0.87)	5.65 (0.96)	15.162	.001	0.457
	F0 Range (Hz)	113.74 (46.53)	124.42 (76.19)	1.114	$n.s.$	
	Intensity Range (dB)	27.68 (2.97)	29.15 (3.90)	4.213	$n.s.$	

M = mean, SD = standard deviation, acoED = Acoustic Euclidean distance between the vowel and /ə/, F0 = fundamental frequency
* *F* (1,18) for global measures, and *F* (1,123) for local measures.

Interaction Between Speaker Group and Passage Position

Table 5 summarizes the interaction between speaker group and passage position. Only intensity range was sensitive to this interaction, *F* (1,18) =4.66, *p*=.044. Specifically, speakers with PD maintained a consistent intensity range from the beginning to the end passage reading, while healthy speakers increased their intensity range at the end of the passage reading.

Table 6. Summary of Statistical Results of Interaction Effects

Measure		$F*$	p	η_p^2
Local	Duration (ms)	.267	$n.s.$	
	Vowel - /ə/ acoED (Hz)	.885	$n.s.$	
Global	Articulation Rate (syl/s)	2.814	$n.s.$	
	F0 Range (Hz)	3.549	$n.s.$	
	Intensity Range (dB)	4.669	.044	.206

acoED = Acoustic Euclidean distance between the vowel and /ə/, F0 = fundamental frequency
* *F* (1,18) for global measures, and *F* (1,123) for local measures.

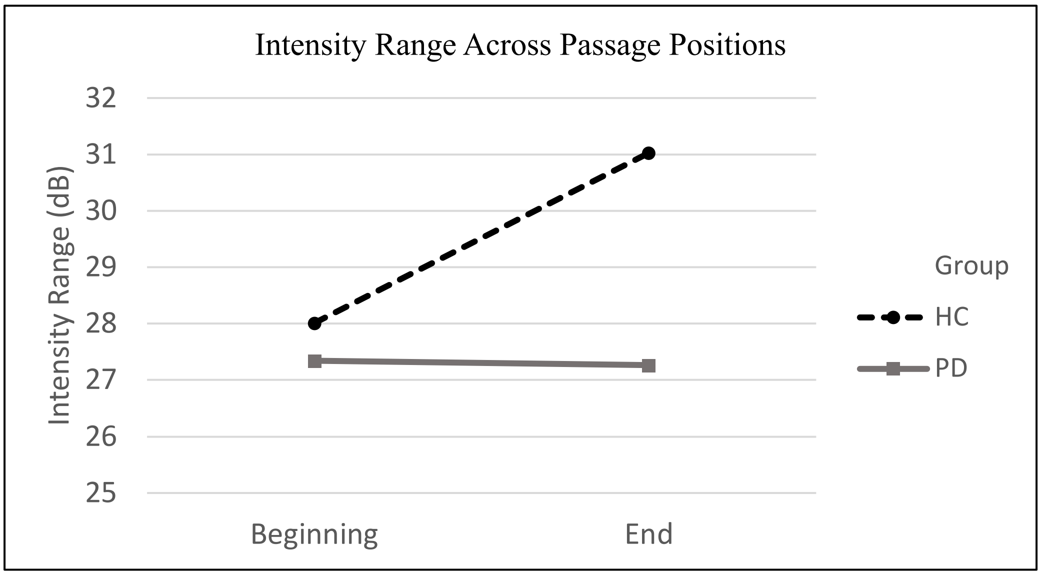

Figure 1.1. Mean Intensity Ranges from the Beginning to End of the Passage Reading

A similar but insignificant trend was observed for F0 range, *F* (1,18) =3.549, *p*=.076.(1,18) = 3.549, *p* = .076. Speakers with PD tended to decrease their F0 range from the beginning to the end of the passage, while healthy speakers tended to increase their F0 ranges.

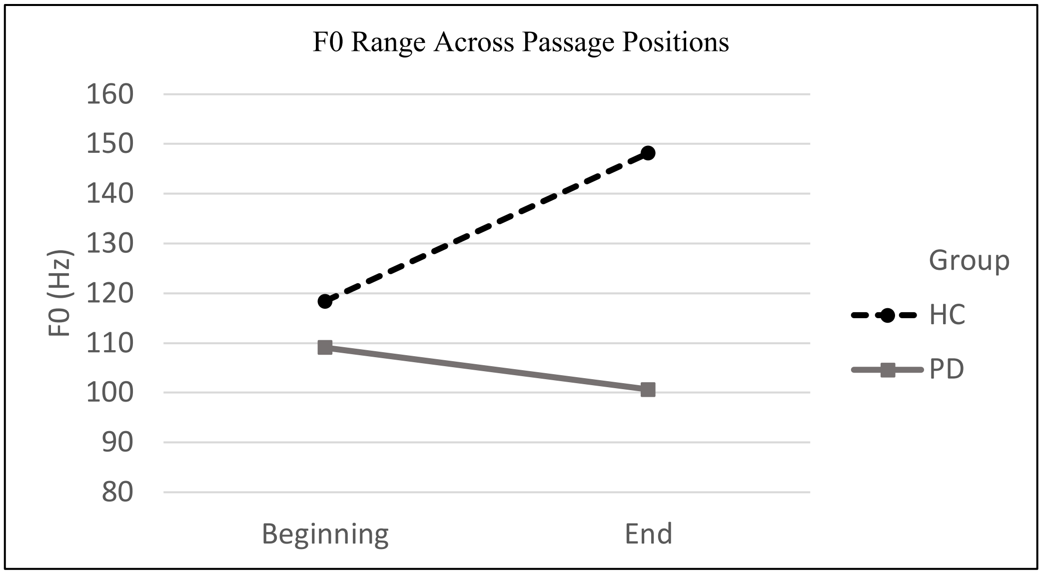

Figure 2.2. Mean F0 Range from the Beginning to End of the Passage Reading

CHAPTER 5. DISCUSSION

The current study aimed to provide acoustic data on speech changes during a passage reading task in speakers with PD compared to neurologically healthy speakers. The study was primarily motivated by a long-standing argument regarding large within-task intraspeaker variability in speech production which is presumably heightened by PD. The findings were expected to provide an insight to selection of speech samples in the studies and assessment of dysarthria secondary to PD.

Speech Characteristics of PD

Despite the overall emphasis of previous literature on prosodic abnormality in speakers with PD such as monopitch, monoloudness, reduced stress, variable rate, short rushes of speech, increase of rate overall (Darley, Aronson, & Brown, 1969), the current study found significant differences between the two speaker groups in two articulation-related, local measures (vowel duration and acoustic Euclidean distance between schwa and corner vowels), but not in the global measures. In general, global measures showed a trend that is consistent with aforementioned perceptual impression. That is, F0 range within utterances was reduced for PD compared to control speakers approximately by 30 Hz. Intensity range was also reduced for PD approximately by 2 dB, although they failed to reach the statistical significance level.

On the other side, the speakers with PD revealed significantly longer vowel durations and reduced Euclidean distance between a central vowel and corner vowels, which consequently indicated a reduction in vowel contrasts (Weimer et al., 2001). Based on the findings, segmental, local acoustic measures were considered to be more sensitive to dysarthria secondary to PD compared to prosodic, global acoustic measures. The importance of segmental articulation measures in identification of dysarthria is consistent with previous literature (e.g., Kim, Kent, & Weismer, 2011).

From Beginning to End of the Passage

It was somewhat surprising that most acoustic measures did not reveal significant position effects. It is possible that the selected passage is not sufficiently long to trigger significant changes in reading as it takes 60-90 seconds to read the passage by average. The results indicated the significant effect of passage position on only one out of 5 measures, articulation rate. For both speaker groups, articulation rate significantly increased toward the end of the passage. This finding is consistent with two previous studies (American English: Kuo & Tjaden, 2016; German: Skodda & Schelegel, 2008). Speakers were capable of retaining the rest of the speech characteristics, vowel duration, Euclidean distance between corner vowels and schwa, and F0/intensity range, until the end of the passage.

Comparison of Speech Changes During Passage Reading between PD and Controls

The primary interest of the current study was the group comparison between speakers with and without dysarthria in terms of acoustic changes throughout passage reading. Significant interaction was found for one acoustic measure, intensity range. That is, speakers with PD showed a slight-to-no decrease in intensity range from the beginning to the end of the passage, while control speakers show an increase in intensity range (Figure 1). Intensity decay in PD has been frequently reported by using vowel prolongation in which speakers with and without PD show a decline in intensity over time (Kent & Kim, 2003; Larson, Ramig, & Scherer, 1994). This finding suggests that speakers with PD are not able to complete laryngeal configurations as quickly as neurologically healthy counterparts (Larson, Ramig, & Scherer, 1994). The current study adds data on intensity changes during a speech task, *passage* reading in PD, which has a different performance expectation compared to vowel prolongation, an *increasing* trend toward the end of the passage. As this is the first document reporting an increase in intensity toward the end of passage reading, a careful interpretation is warranted in case this pattern is limited to *The Caterpillar* passage. This is because the last part of the passage includes words with emphatic stress and ends with an exclamation point.

The same pattern was also observed for F0 range, which is not surprising in consideration of a similar pattern between the two parameters in general. That is, speakers with PD showed a slight decline in F0 range while control speakers showed a dramatic increase in the measure. However, F0 range missed the statistical significance (p = .076). Taken together, it is speculated that speakers with PD show limited variation in prosody, which becomes apparent toward the end of passage reading.

Clinical Implications

The current study has clinical implications regarding the methods used in the evaluation of speech disturbances in PD, especially concerning the speech stimuli and the measures derived from said stimuli. As previously mentioned, passage reading is advantageous in that it resembles connected speech and is, therefore, more ecologically valid. However, the findings of the current study highlight the importance of where acoustic measures are derived from within the passage (i.e., beginning of the passage vs. end of the passage). Specifically, prosodic disturbances within PD will likely be more apparent near the end of passage reading compared to the beginning of the passage, where speakers with PD's prosody is comparable to that of the healthy speakers.

Additionally, the current study has implications for the type of measures used to examine speech disturbances in PD (i.e., local vs. global measures). When examining group differences between speakers with PD and healthy speakers, local vowel-level measures were sensitive to the group differences while the global utterance-level measures were not. These findings have implications for the types of measures selected to examine group differences between PD speakers and healthy speakers.

Limitations and Future Direction

The current study has some limitations. First, limited acoustic measures were included in the study due to feasibility considerations. An extended set of acoustic measures that are known to be sensitive to dysarthria such as second formant frequency (F2) slope may strengthen the findings. Related to this, the scope of the study was limited to acoustic data, although speech recordings were obtained for both acoustic and acoustic data. Future studies will follow examining articulatory kinematic changes within passage reading as well as auditory perceptual changes (i.e., speech intelligibility ratings). Second, the study included a relatively small sample size; therefore, this information may not be representative of the entire population. Future studies should incorporate a larger sample size. Third, although it is well documented that PD is more frequent in men than women, the majority of participants of this study was men. Due to this, results may not fairly represent the results for female speakers.

APPENDIX A

The Caterpillar by Rita Patel et al., 2013

Do you like amusement parks? Well, I sure do. To amuse myself, I went twice last spring. My most MEMORABLE moment was riding on the Caterpillar, which is a gigantic roller coaster high above the ground. When I saw how high the Caterpillar rose into the bright blue sky I knew it was for me. After waiting in line for thirty minutes, I made it to the front where the man measured my height to see if I was tall enough. I gave the man my coins, asked for change, and jumped on the cart. Tick, tick, tick, the Caterpillar climbed slowly up the tracks. It went SO high I could see the parking lot. Boy was I SCARED! I thought to myself, “There’s no turning back now.” People were so scared they screamed as we swiftly zoomed fast, fast, and faster along the tracks. As quickly as it started, the Caterpillar came to a stop. Unfortunately, it was time to pack the car and drive home. That night I dreamt of the wild ride on the Caterpillar. Taking a trip to the amusement park and riding on the Caterpillar was my MOST memorable moment ever!

REFERENCES

Ackermann et al., H. (1997). Kinematic analysis of articulatory movements in cental motor disorders. *Movement Disorders*, 1019-1027.

Barlow, S., Weismer, G., Smith, A., & Caviness, J. (2008). Special Panel Session: Driving Critical Initiatives in Motor Speech. *Journal of medical speech-language pathology, 16*(4), 283-283.

Bradlow, A. R., Toretta, G. M., & Pisoni, D. B. (1996). Intelligibility of normal speech I: Global and fine-grained acoustic phonetic talker characteristics. *Speech Communication, 20*(3-4), 255-272.

Bunton, K., & Weismer, G. (2002). Segmental level analysis of laryngeal function in persons with motor speech disorders. *Folia Phoniatrica et Logopaedia, 54*, 223-239.

Bunton, K., Kent, R. D., Duffy, J. R., Rosenbeck, J. C., & Kent, J. F. (2007). Listener Agreement for Auditory-Perceptual Ratings of Dysarthria. *Journal of Speech, Language, and Hearing Research, 50*, 1481-1495.

Caligiuri, M. (1987). Labial kinematics during speech in patients with parkinsonian rigidity. *Brain, 110*, 1033-1044.

Canter, G. J. (1963). Speech characteristics of patients with Parkinson's disease: I. Intensity, pitch, and duration. *Journal of Speech and Hearing Disorders, 23*, 221-229.

Chaudhuri, K. (2006). Non-motor symptoms of Parkinson's disease: Diagnosis and management. *The Lancet. Neurology, 5*(3), 235-245. doi:10.1016/S1474-4422(06)70373-8

Connor et al., N. (1989). Parkinsonian deficits in serial multiarticulate movements for speech. *Brain, 117*, 997-1009.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1969b). Clusters of deviant speech dimensions in the dysarthrias. *Journal of Speech, Language, and Hearing Research, 12*(3), 462-496.

Darley, F., Aronson, A., & Brown, J. (1969a). Differential diagnostic patterns of dysarthria. *Journal of Speech, Language, and Hearing Research, 12*(2), 246-269.

Dromey , C., Hunter , E., & Nissen, S. (2018). Speech adaptation to kinematic recording sensors: Perceptual and acoustic findings. *Journal of Speech, Language, and Hearing Research, 61*(3), 593-603.

Duffy, J. R. (1995). *Motor speech disorders: substrates, differential diagnosis, and management.* St. Louis : Mosby.

Duffy, J. R. (2013). *Motor Speech Disorders: Substrates, differential diagnosis, and management.* St Louis: Elsevier Mosby.

Erro, R., & Stamelou, M. (2017). The motor syndrome of Parkinson's disease. *International review of neurobiology, 132*, 25-32. doi:10.1016/bs.irn.2017.01.004

Feenaughty, L., Tjaden, K., & Sussman, J. (2014). Relationship between acoustic measures and judgements of intelligibility in parkinson's disease: A within-speaker approach. *Clinical linguistics & phonetics, 28*(11), 857-978.

Fischer , E., & Goberman, A. M. (2009). Voice onset time in parkinson disease. *Journal of Communication Disorders, 43*(1), 21-34.

Flint, A., Black, S., Campbell-Taylor, I., Gailey, G., & Levinton, C. (1992). Acoustic analysis in the differentiation between parkinson's disease and major depression. *Journal of Psycholinguistic Research, 21*, 383-399.

Forrest , K., & Weismer , G. (1995). Dynamic aspects of lower lip movement in parkinsonian and neurologically normal geriatric speakers' production of stress. *Journal of Speech and Hearing Research, 38*, 260-272.

Forrest, K., Weismer, G., & Turner, G. (1989). Kinematic, acoustic, and perceptual analyses of connected speech produced by parkinsonian and normal geriatric males. *Journal of the Acoustical Society of America*, 2608-2622.

Gironell et al. (2018). Tremor types in parkinson's disease: A descriptive study using a new classification. *Parkinson's Disease*, n.a. doi:10.1155/2018/4327597

Goedert, M. (2015). Neurodegeneration. Alzheimer's and parkinson's: The prion concept in relation to assembled Aβ, tau, and α-synuclein. *Science, 349*(6248), 601-611.

Gray, W. S. (1936). *Standard oral reading paragraphs: My grandfather.* Bloomington, IL: Public School Publishing Company.

Grewel, F. (1957). Dysarthria in post-encephalitic parkinsonism. *Acta Psychiatr. Neurol. Scand., 32*, 440-449.

Hammen, V., & Yorkston, K. M. (1996). Speech and pause characteristics following speech rate reduction in hypokinetic dysarthria. *Journal of Communication Disorders, 29*(6), 429-445. doi:10.1016/0021-9924(95)00037-2

Harel et al., B. (2004). Acoustic characteristics of Parkinsonian speech: A potential biomarker of early disease progression and treatment. *Journal of Neurolinguistics, 17*, 439-453.

Hirose, H., Kiritani, S., Ushijima, T., Yoshioka, H., & Sawashima, M. (1981). Patterns of dysarthric movements in patients with parkinsonism. *Folia Phoniatrica et Logopaedia, 33*, 204-215.

Hsu, S. C., Jiao, Y., McAuliffe, M. J., Berisha, V., Wu, R. M., & Levy, E. S. (2017). Acoustic and perceputal speech characteristics of native Mandarin speakers with parkinson's disease. *The Journal of the Acoustical Society of America, 141*(3), EL293-EL299.

Johnson, K. (2003). Chapter 9: Nasals and Laterals. In *Acoustic and auditory phonetics* (2nd Edition ed., pp. 149-168). Malden: Blackwell Publications.

Karnell , L. H., Funk , G. F., Tomblin, J. B., & Hoffman , H. T. (1999). Quality of life measurements of speech in the head and neck cancer patient population. *Head and Neck, 21*, 229-238.

Kent , R. D., & Kim, Y. J. (2003). Toward an acoustic typology of motor speech disorders. *Clinical Linguistics and Phonetics, 17*(6), 427-445.

Kent , R., & Netsell, R. (1978). Articulatory abnomalities in athetoid cerebral palsy. *Journal of Speech and Hearing Disorders, 43*, 353-373.

Kent , R., Netsell, R., & Bauer, L. L. (1975). Cineradiographic assessment of articulatory mobility in the dysarthrias. *Journal of Speech and Hearing Disorders, 40*, 467-480.

Kim, Y., Kent , R., & Weismer, G. (2011). An acoustic study of the relationships among neurologic disease, dysathria type, and severity of dysarthia. *Journal of Speech Language and Hearing Research, 54*(2), 417-429.

Kim, Y., Weismer, G., Kent, R. D., & Duffy, J. R. (2009). Statistical models of F2 slope in relation to severity of dysarthria. *Folia Phoniatrica et Logopaedica, 61*(6), 329-335.

Kuo, C. (2017). Vowel contrasts relative to schwa across tasks: Preliminary findings for Parkinson's disease. *The Journal of the Acoustical Society of America, 141*, 3840.

Kuo, C. (2017). Vowel contrasts relative to schwa: effects of utterance-level fundamental frequency. *The Journal of Acoustical Society of America, 142*(4), 2584.

Kuo, C., & Tjaden, K. (2016). Acoustic variation during passage reading for speakers with dysarthria and healthy controls. *Journal of Communication Disorders, 62*, 30-44. doi:10.1016/j.jcomdis.2016.05.003

Lam, J., & Tjaden, K. (2016). Clear speech variants: An acoustic study in parkinson's disease. *Journal of Speech, Language, and Hearing Research, 59*(4), 631-646.

Larson, K., Ramig, L., & Scherer, R. (1994). Acoustic and glottographic voice analysis during drug-related fluctuations in Parkinson's disease. *Journal of Medical Speech Language Pathology, 2*(227).

Lindblom, B. (1963). Spectrographic study of vowel reduction. *Journal of the Acoustical Society of America, 35*, 1773-1781.

Ludlow, C. L., Connor , N. P., & Bassich, C. J. (1987). Speech timing in Parkinson's and Huntington's disease. *Brain Lang, 32*(2), 195-214.

McRae, P. A., Tjaden, K., & Schoonings, B. (2002). Acoustic and perceptual consequences of articulatory rate change in parkinson disease. *Journal of Speech, Language, and Hearing Research, 45*(1), 35-50.

Milenkovic, P. (2005). TF32 [Computer software]. Madison, WI; University of Wisconsin-Madison.

Miller et al. (2007). Prevalence and pattern of perceived intelligibility changes in parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 78*(11), 1188-1190. doi:10.1136/jnnp.2006.110171

Northern Digitital Inc. (n.d.). Wave System. Waterloo, Ontario, Canada.

Parashar, A., & Udayabanu, M. (2017). Gut microbiota: Implications in parkinson's disease. *Parkinsonism & related disorders, 38*, 1-7.

Patel, R., Connaghan, K., Franco, D., Edsall, D., Forgit, D., Olsen, L., . . . Russell, S. (2013). “The Caterpillar”: A Novel Reading Passage for Assessment of Motor Speech Disorders. *American Journal of Speech-Language Pathology, 22*(1), 1-9.

Picheny, M. A., Durlach, N. I., & Braida, L. D. (1985). Speaking clearly for the hard of hearing I: Intelligibility differences between clear and conversational speech. *Journal of Speech and Hearing Research, 28*(1), 96-103.

Postuma, e. (2015). MDS clinical diagnostic criteria for parkinson's disease. *Movement disorders: official journal for the movement disorder society, 12*, 1591-1601. doi:10.1002/mds.26424

Rusz, J., Cmejla, R., Ruzickova, H., & Ruzicka , E. (2011). Quantitative acoustic measures for characterization of speech and voice disorders in early untreated parkinson's disease. *The Journal of the Acoustical Society of America, 129*(1), 350-367.

Sapir, S., Ramig, L. O., Spielman, J. L., & Fox, C. (2010). Formant centralization ratio: A proposal for a new acoustic measure of dysarthric speech. *Journal of Speech, Language, and Hearing Research, 53*(1), 114-125.

Sapir, S., Spielman, J. L., Ramig, L. O., Story, B. H., & Fox, C. (2007). Effects of intensive voice treatment (the lee silverman voice treatment [lsvt]) on vowel articulation in dysarthric individuals with idiopathic parkinson disease: Acoustic and perceptual findings. *Journal of speech, language, and hearing research, 50*(4), 899-912.

Scheperjans et al, F. (2015). Gut microbiota are related to parkinson's disease and clinical phenotype. *Movement Disorders, 30*(3), 350-358.

Shapira, A., Chaudhuri, K., & Jenner, P. (2017). Non-motor features of Parkinson disease. *Nature Reviews. Neuroscience.*, 435-450. doi:10.1038/nrn.2017.62

Skodda, S., & Schlegel, U. (2008). Speech rate and rhythm in parkinson's disease. *Movement Disorders, 23*, 985-992.

Solomon, N. (2009). Vocal fatigue and its relation to vocal hyperfunction. *Internation Journal of Speech-Language Pathology, 10*(4), 254-266.

Tjaden, K., & Wilding, G. (2004). Rate and loudness manipulations in dysarthria: Acoustic and perceptual findings. *Journal of Speech, Language, and Hearing Research, 47*, 766-783.

Tjaden, K., Lam, J., & Wilding, G. (2013). Vowel acoustics in parkinson's disease and multiple sclerosis: Comparison of clear, loud, and slow speaking conditions. *Journal of Speech, Language, and Hearing Research, 56*(5), 1485-1502.

Turner, G. S., Tjaden, K., & Weismer, G. (1995). The influence of speaking rate on vowel space area and speech intelligibility for individuals with amyotrophic lateral sclerosis. *Journal of Speech and Hearing Research, 38*(5), 1001-1013.

Weismer , G. (1991). Assessment of articulatory timing. In J. A. Cooper, *Assessment of speech and voice production: Research and clinical applications (NIDCD Monograph)* (Vol. 1, pp. 84-95). Bethesda, MD: National Institutes of Health.

Weismer, G. (1984). Articulatory characteristics of Parkinsonian dysarthria: Segmental and phrase level timing, spirantization, and glottal-supraglottal coordination. In M. M. McNeil, J. C. Rosenbek, & A. E. Aronson (Eds), *The dysarthrias: Physiology, acousics, perception, management* (pp. 100-130). San Diego: College-Hill.

Weismer, G. (2007). *Motor Speech Disorders.* San Diego: Plural Publishing Inc.

Weismer, G., Jeng, J. Y., Laures, R. D., & Kent, J. F. (2001). Acoustic and intelligibility characteristics of sentence production in neurogenic speech disorders. *Folia Phoniatrica et Logopaedica, 53*(1), 1-18.

Whitfield, J. A., & Goberman, A. M. (2017). Articulatory-acoustic vowel space: Associations between acoustic and perceptual measures of clear speech. *International Journal of Speech-Language Pathology, 19*(2), 184-194.

Whitfield, J. A., & Mehta, D. D. (2019). Examination of clear speech in parkinson disease using measures of working vowel space. *Journal of Speech, Language, and Hearing Research, 62*, 2082-2098.

Wong , L. (2014). Kinematic and correlational analyses on labial and lingual functions during syllable repetitions in Cantonese dysarthric speakers with Parkinson's disease of varying severity using electromagnetic articulography (EMA). Retrieved from http://hdl.handle.net/10722/238930

Wong , M. N., Murdoch, B. E., & Whelan, B. (2010). Kinematic analysis of lingual function dysarthric in speakers with parkinson's disease: an electromagnetic articulograph study. *International Joural of Speech-Language Pathology, 12*(5), 414-425.

Yunusova, Y., Weismer, G., Westbury, J. R., & Lindstrom, M. J. (2008). Articulatory movements during vowels in speakers with dysarthria and healthy controls. *Journal of Speech, Language, and Hearing Research, 51*, 596-611.

Zeplin, J., & Kent, R. S. (1996). Reliability of auditory perceptual scaling of dysarthria. In D. Robin, K. Yorkson, & D. R. Buekelman (Eds.), *Disorders of motor speech: Recent advances in assessment, treatment, and clinical characterization.* Baltimore: Paul H. Brookes.

Zyski, B. J., & Weisiger, B. E. (1987). Identification of dysarthria types based on perceptual analysis. *Journal of Communication Disorders, 20*, 367-378.

VITA

Kimberly Clarissa Grubbs, born in Gulfport, MS, gained her undergraduate degree in Speech Language Pathology and Audiology from The University of Southern Mississippi in May of 2018. At The University of Southern Mississippi, Kimberly was a Ronald E. McNair scholar, where her passion for research flourished. Kimberly then attended Louisiana State University to anticipate graduating with her Master of Arts in Communication Sciences in Disorders in May of 2020. Upon completion of her master's degree, she will work as a Speech-Language Pathologist Clinical Fellow.