THE EFFECT OF PARKINSON'S DISEASE ON PROSODY IN CONNECTED SPEECH

by

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Submitted in partial fulfillment of the

requirements for Departmental Honors

in the Department of Speech-Language Pathology

Texas Christian University

Fort Worth, Texas

May 6, 2019

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PROSODY IN CONNECTED SPEECH

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ABSTRACT

Dysprosody is a feature of disordered communication among individuals with Parkinson's disease (PD). Unfortunately, the literature does not quantify the extent to which dysprosody contributes to overall communication impairment associated with the disease. The purpose of this research is to examine: 1) whether the prosody of connected speech in adults with Parkinson's disease is different than that of neurologically healthy older adults, and 2) whether prosody varies across different speaking conditions. Adults with PD ($n = 20$) and without PD ($n = 20$) completed three connected speech tasks. Average changes in 1) frequency and 2) intensity from stressed to unstressed syllables in multisyllabic words, as well as 3) speech rate were measured across speaking conditions. Two-way ANOVAs revealed statistically significant differences across all three dependent variables ($p < 0.05$). Post-hoc testing identified within-subjects or between-subjects differences across all variables, suggesting that some adults with PD may tend to vary prosody more robustly than their healthy adult counterparts in certain speech contexts. These findings somewhat contradict the literature and may be attributed to compensatory strategies employed by subjects with less severe PD. Replication with a larger sample size is necessary to determine clinical significance; however, if merited, these results may suggest that prosody is of lesser initial concern in patients with PD than are other aspects of communication decline.

Introduction

Parkinson's disease (PD) is a progressive neurological disease reported as the second-most common neurodegenerative disease after Alzheimer's (Lebouvier et al., 2009). Symptoms often vary individually, but the disease is broadly characterized by decreased motor function alongside a breadth of non-motor impairments. The exact cause of PD remains unknown, but stems from lowered levels of dopamine (a neurotransmitter within the brain) as a result of neural cell death (Bartels & Leenders, 2009). Clinical diagnosis of Parkinson's disease is difficult due to widely varying symptoms and lack of a straightforward testing method. However, to confirm a diagnosis, one must generally exhibit at least two of the four primary symptoms (tremor, muscular rigidity, bradykinesia, and postural instability; Farlow, Pankratz, Wojcieszek, & Foroud, 2004). A diagnostic support also includes a positive response to levodopa, a drug which temporarily restores dopamine levels within the brain and may allow a reprieve from motor symptoms (Farlow, Pankratz, Wojcieszek, & Foroud, 2004). A key issue surrounding Parkinson's disease is that it is often not diagnosed until the patient has lived with the insidious non-motor symptoms for an extended time, often not acknowledging any issues until motor difficulties appear. The problem that opens opportunities for further research is the lack of early markers that, when detected, would allow for earlier intervention and highly specialized treatment to prevent the disease from running its full course or, at the very least, slowing the progression of impairments and preserving an individual's quality of life for as long as possible.

Parkinson's disease affects several areas of communication, including voice production, speech and articulation ability, and prosodic capability. The voice impairments of PD include increased phonation effort, decreased pitch range, vocal fold abnormalities, and vocal tremor. These abnormalities result in the perception of dysphonia, which is often described by listeners as harshness and breathiness (Tjaden, 2008). Ikui et al. (2015) compared vocal pitch range for 30 patients with PD and compared them with 30 neurologically healthy, age-matched speakers and generally found voice pitch range to narrow significantly for moth males and females. Stelzig, Hochhaus, Gall, and Henneberg (1999) also noted rampant gender differences in voice abnormalities within Parkinson's disease.

Parkinson's disease also hinders articulation abilities. It has been previously established that hypokinetic dysarthria is a common feature of PD. Approximately 90% of people with PD develop dysarthric speech during the disease's course; while most present with hypokinetic dysarthria, 10-20% have mixed hypokinetic-hyperkinetic dysarthria (Tjaden, 2008). To clarify, hypokinetic refers to decreased body motion, while hyperkinetic corresponds with increased involuntary movements (in this case, due to basal ganglia control circuit pathology). Hypokinetic dysarthria in PD results in reduced stress, imprecise articulation, short rushes of speech, and hesitant/dysfluent speech, in addition to voice-related symptoms (Darley, Aronson, & Brown, 1969 and Darley, Aronson, & Brown, 1969). Other difficulties in articulation involve timing of vocal onset/offset, range of vowel articulation, and spirantization (production of a fricative during stop closures; Ramig, Fox, & Sapir, 2008), as well as short phrases, variable rate, overall increased rate, inappropriate silences, repeated phonemes, and imprecise consonants.

With regard to speech ability, speakers with PD often demonstrate reduced movement velocity/displacement of the velum. Also reduced are peak movement velocity/amplitude of the lips and jaw. These differences are shown by 'reduced vowel formant transition extents and slopes, a collapsed vowel acoustic working space, and a trend toward reduced consonant spectral distinctiveness' (Tjaden, 2008). Skodda, Grönheit, and Schlegel (2012) calculated triangular vowel space area (tVSA) and vowel articulation index (VAI) in patients with PD compared with normal speakers. They found that VAI values were decreased over time in the Parkinson's group, and the tVSA measurements also showed reduction between the first and second examination – just as with the VAI measurement – but only in females with PD (Skodda, Grönheit, & Schlegel, 2012). Persons with PD are often harder to understand than their healthy older adult counterparts. Miller et al. (2007) reported that speech intelligibility is greatly reduced in Parkinson's disease; approximately 70% of people with PD fell below the control mean of unaffected speakers in a study of 125 people with PD (Miller, 2007). It is also worth noting that dysfluency is common in around 15-45% of patients with PD (Tjaden, 2008).

Prosody, or the melody of someone's speech, is a key aspect of communication that also suffers with the progression of PD – a concept known as dysprosody. Dysprosody in patients with PD is observed in several manners, including reduced stress, flat speech melody/pitch range (monopitch), impairment of speech intensity control (monoloudness), altered rhythm/speech rate, inappropriate silences, and short rushes of speech (Galaz et al., 2016; Duffy, 2005). Dysprosody is detrimental to speech intelligibility and naturalness. Pell, Cheang, and Leonard (2006) reported that PD speakers less effectively produced stress distinctions. The listeners who analyzed their speech had more difficulty detecting the "emotional qualities" of their speech, and more often rated their utterances as "sad" or "devoid of emotion/neutral." Another feature of Parkinsonian dysprosody is reduced pitch range; female patients with PD seem to demonstrate greater decline in pitch variability (Skodda, Grönheit, Mancinelli, & Schlegel, 2013). The defining clinical marker also points to a limited range of fundamental frequency in both males and females with PD (Galaz et al, 2016; Skodda, Grönheit, Mancinelli, & Schlegel, 2013). Monoloudness, or a reduction in the variability of speech intensity, is also of concern in PD patients. In 2000, Holmes, Oates, and Phyland reported limited loudness variability, and noted that it was worse in later stages of PD. Researchers have also seen variable speaking rates in subjects with PD. While some individuals speak at a normal rate, others are perceived to speak more slowly or rapidly (Duffy, 2005; Huber & Darling, 2011; Martínez-Sánchez et al., 2015).

Research efforts currently seek to identify potential markers for early detection of PD. Presently, the literature describes examples of voice, articulation, and prosodic changes in individuals with PD, but does not investigate the relationships between those categories. In other words, there exists no defining body of work determining whether persons with PD tend to experience all three types of changes, if voice changes tend to precede articulation changes, or if early-detected prosodic changes tend to predict further communication decline as the disease progresses, for instance. Potentially, altered speech prosody could reveal biomarkers for development of PD. For example, Harel, Cannizzaro, Cohen, Reilly, and Snyder (2004) specifically suggest that changes in the variability of speakers' fundamental frequency might lead to earlier detection of disease presence. Therefore, it becomes crucial to develop an accurate, representative method of measuring speech prosody while comparing prosodic characteristics within and among populations with and without PD.

It is possible that speakers with PD tend to experience changes in speech prosody to a greater or lesser degree than they experience changes in voice quality or articulation ability; however, research evidence is needed to identify the extent to which speakers with PD tend to deviate from their healthy older adult (HOA) counterparts in prosodic characteristics in order to investigate this hypothesis. By potentially identifying a correlation between prosodic differences and the presence and/or stages of PD, future research may establish better methods of identifying markers of PD, whether within a diagnostic test battery, annual wellness check-ups, or through listener perceptions.

Methods

Participants

This study included data collected from twenty speakers with Parkinson's disease (10 females, 10 males) and twenty healthy adults without Parkinson's disease (15 females, 5 males) who served as a control group. The inclusion criteria for the participants with Parkinson's disease required a diagnosis of Parkinson's disease from a neurologist, an age of 40 and above, and the absence of comorbid neurological or respiratory conditions. Inclusion criteria for the healthy adult participants included an age of 40 and above, no Parkinson's disease, no neurological and respiratory conditions, and no speech and voice impairments.

Instrumentation

For audio recordings, participants wore an AKG C 520 Headworn Condenser Microphone. This microphone was selected for its ability to collect an accurate speech signal. The microphone's cardioid polar pattern allowed for collection of soundwaves anteriorly and laterally, but not posteriorly where distracting noise is often located. Additionally, its flat frequency response from 20-20,000 Hz enabled the microphone to equally detect all signals within the frequency range, creating a comprehensive acoustic representation of each subject's speech. Additionally, a Behringer U-Phoria UMC22 pre-amplifier used in conjunction with the microphone served as a filter to process a clear, high-quality with minimal background noise.

Procedures

Participants completed one visit each for the study. Visits took place in the Laryngeal Function Lab in Texas Christian University's Miller Speech and Hearing Clinic or at classroom locations arranged with Dr. Nina Mosier, director of Power for Parkinson's in Austin, Texas. Power for Parkinson's is a non-profit organization that provides "free exercise, dance, and singing classes in-person in Austin, and globally via home videos" to individuals with PD and their caregivers. Full participation in the study comprised a thirty- to forty-five minute session, including the description of testing procedures, verification of inclusion criteria, completion of the consent form and HIPAA forms, completion of testing procedures, and any necessary debriefing.

Both the experimental and the control groups followed the same data collection protocol. During recording, each participant completed three speaking tasks:

A. Produce spontaneous connected speech in response to two prompts from the study investigator:
    1. "Tell me how to make a peanut butter and jelly sandwich."
    2. "Tell me about your favorite movie."
B. Read aloud the Rainbow Passage, an elicitation passage with a balance of English speech sounds.
C. Read aloud the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) sentences, a list of six sentences designed to elicit various laryngeal behaviors.

The order in which these tasks were completed was counterbalanced within each group, meaning that some participants completed task A first, followed by task B then C, and others completed task B first, followed by task A then C, and so on until all combinations were approximately equally achieved. This counterbalance acted as a control against the possibility of skewing study results due to vocal fatigue over the duration of the study visit. Participants were randomly assigned to an order of tasks via random number generator. Participants were also prompted to silently read the Rainbow passage and CAPE-V sentences in order to familiarize themselves with the language of those tasks before reading aloud.

Measurements

Each sample was analyzed using specialized software (Praat – Paul Boersma & David Weenink, Institute of Phonetic Sciences, University of Amsterdam, The Netherlands; www.praat.org). Three dependent variables were measured as comprehensive metrics for prosodic variation: 1) the change in frequency between stressed and unstressed syllables in multisyllabic words; 2) the change in intensity between stressed and unstressed syllables in multisyllabic words; and 3) the speech rate in syllables per second. The change in frequency and intensity were measured by visually selecting constituent syllables from multisyllabic words (e.g., /mu/ and /vi/ from the word "movie") and measuring the average frequency and intensity of each syllable. Seven multisyllabic words from each of the two question prompts, seven from the Rainbow passage, and three from the CAPE-V sentences were selected for each participant, and an average across multisyllables was calculated for each speaking condition. A similar procedure was followed to obtain average speech rate: the second and third utterances from each of the question prompts, the second and third sentences from the Rainbow passage, and the third sentence from the CAPE-V sentences were selected. The number of syllables in each utterance was divided by the length of the recording to calculate the average number of syllables per second.

Results

Data from the healthy adult speakers and speakers with PD were collated into separate data sets, and are provided in Table 1. Once all data were collected, three two-way mixed model

Analysis of Variance (ANOVA) tests were conducted for the three dependent variables via Statistical Package for Social Science (SPSS) software to determine if the dependent variables were different as a function of group in each speaking condition. The group (PD vs. control) served as the between-subjects factor and the speaking conditions (questions, Rainbow passage, and CAPE-V sentences) served as within-subjects factors.

Table 1. Descriptive statistics for measurements of dependent variables by group and speaking condition (prompt)

Prompt	**Group**	**Mean ΔFrequency (Hz)** (***standard deviation***)	**Mean ΔIntensity (dB)** ***(standard deviation)***	**Mean Rate (syllables/second)** ***(standard deviation)***
Question	Control	2.3154	-.5382	4.9548
		(11.39187)	*(2.76207)*	*(0.64255)*
	PD	-4.6525	-.7898	4.5346
		(6.40093)	*(2.42964)*	*(0.82534)*
Rainbow	Control	-2.0462	-2.0619	4.7773
		(13.60688)	*(4.16143)*	*(0.51306)*
	PD	-5.2555	-2.7776	4.0822
		(10.47716)	*(3.52173)*	*(0.61816)*
CAPE-V	Control	3.9010	-.6695	5.2477
		(25.26758)	*(1.34696)*	*(0.55756)*
	PD	-7.2760	-1.6880	4.9063
		(25.87285)	*(1.79419)*	*(0.83948)*

The descriptive statistics of the table above reveal overall group trends for each speaking condition. When responding to question prompts, reading the Rainbow passage, and reading CAPE-V sentences, the experimental (PD) group showed greater variation in frequency between stressed and unstressed syllables. The greater absolute value of that group's distance from zero in the table indicates the larger distinction between stressed and unstressed syllables; the negative value indicates that this particular group tended to produce stressed syllables that were higher in frequency than their corresponding unstressed syllables in all three speaking conditions. Conversely, the positive value for the control group in the questions prompt indicates that, on average, that group tended to produce stressed syllables lower in frequency than unstressed counterparts. The experimental group also appeared to vary intensity between stressed and unstressed syllables more robustly than the control group across all three speaking conditions. Finally, across all speaking conditions, the experimental group appeared to speak between one half to three quarters of a syllable more slowly than the control group.

Group data for frequency measures are illustrated in Figures 1 and 2. ANOVA results for frequency did not show statistical significance for within-subjects effects ($F = 0.219$, $p = 0.814$), but was significant for between-subjects effects ($F = 5.853$, $p = 0.02$), meaning that a group difference existed in frequency variation. Changes in frequency were not different based on which group spoke in a given condition—that is, no interaction effect was found for frequency ($F = 0.507$, $p = 0.556$). A post-hoc Mann-Whitney U test indicated that significant group differences occurred within the question prompts and the CAPE-V sentences ($p = 0.045$ and $p = 0.037$, respectively). In other words, the experimental group tended to vary frequency between stressed and unstressed syllables more than the control group when responding to questions and when reading CAPE-V sentences.

Figure 1. Average group change in frequency among multisyllabic words in question prompts

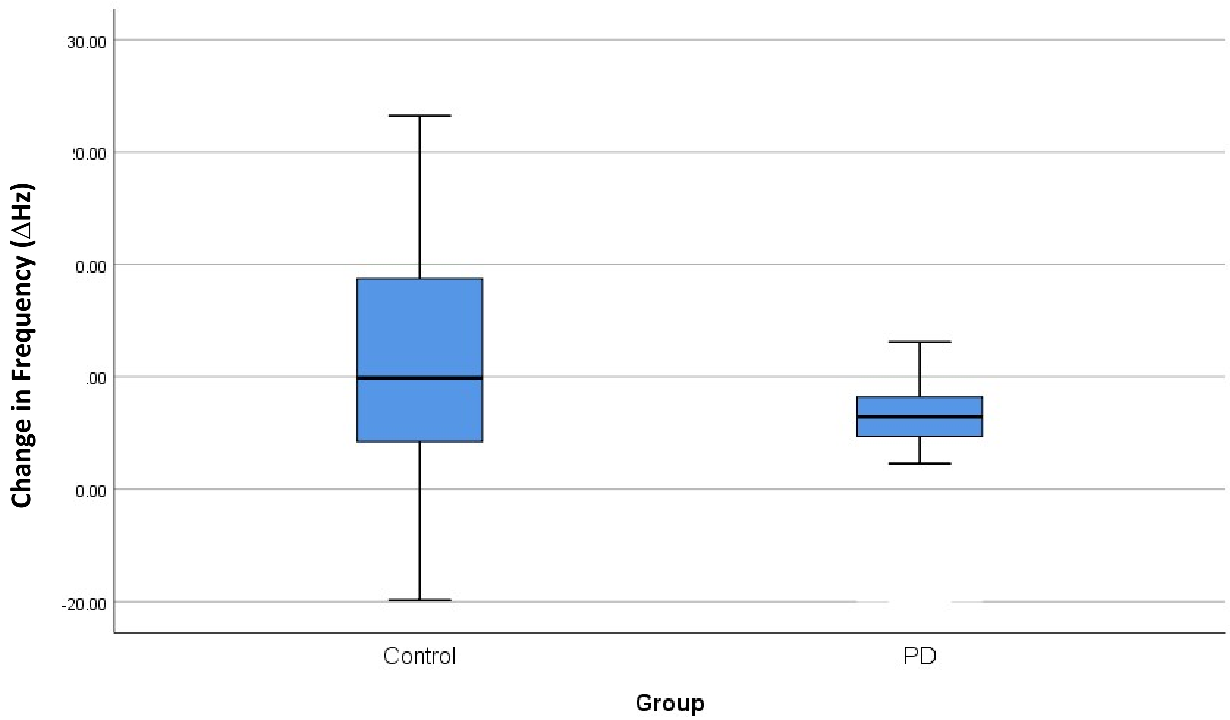
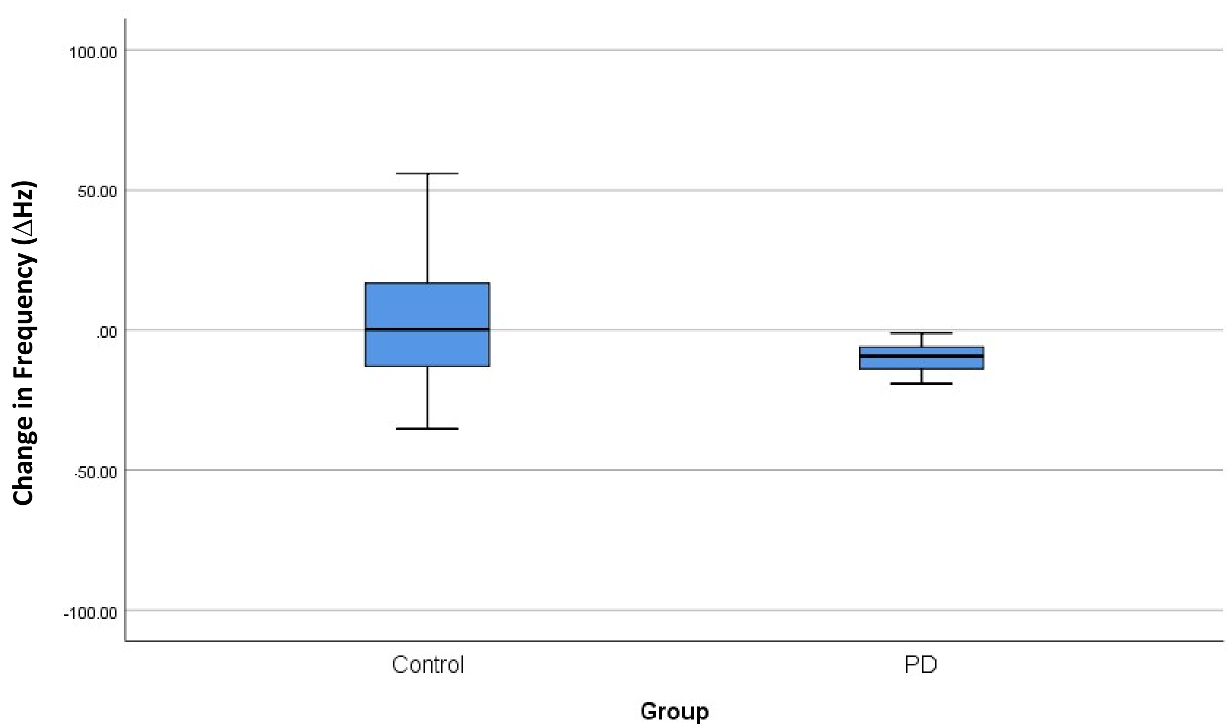
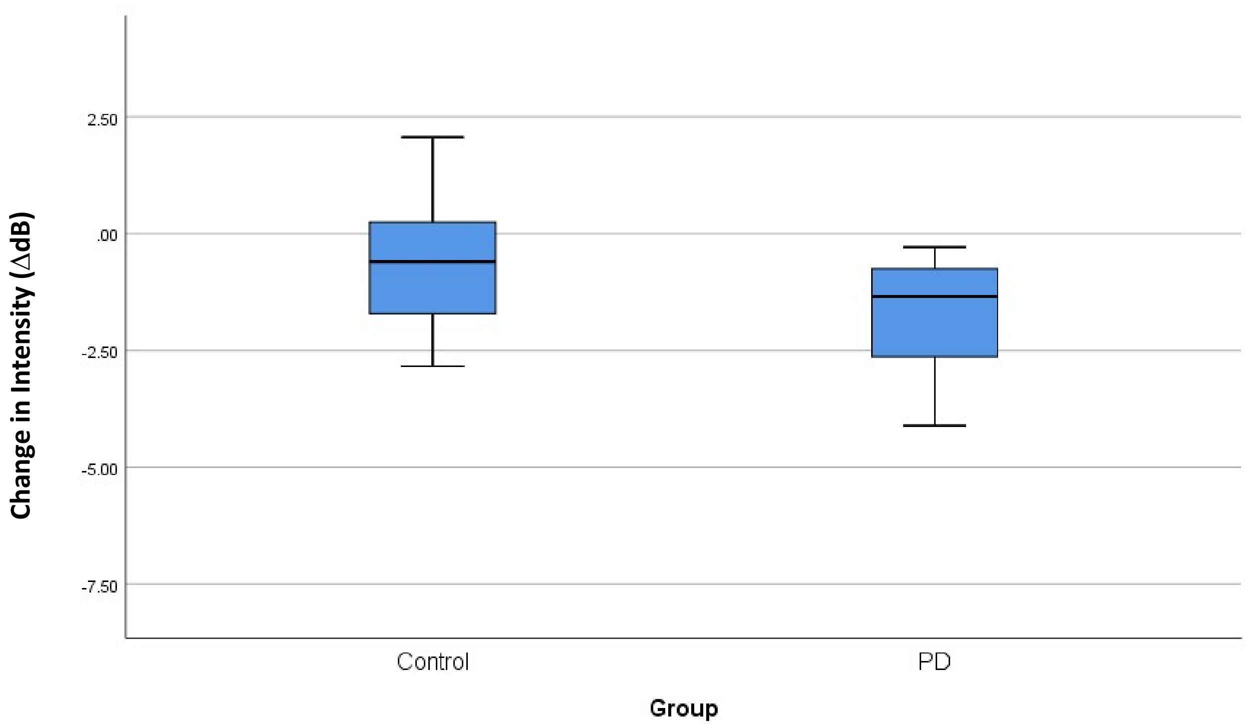


Figure 2. Average group change in frequency among multisyllabic words in CAPE-V sentences



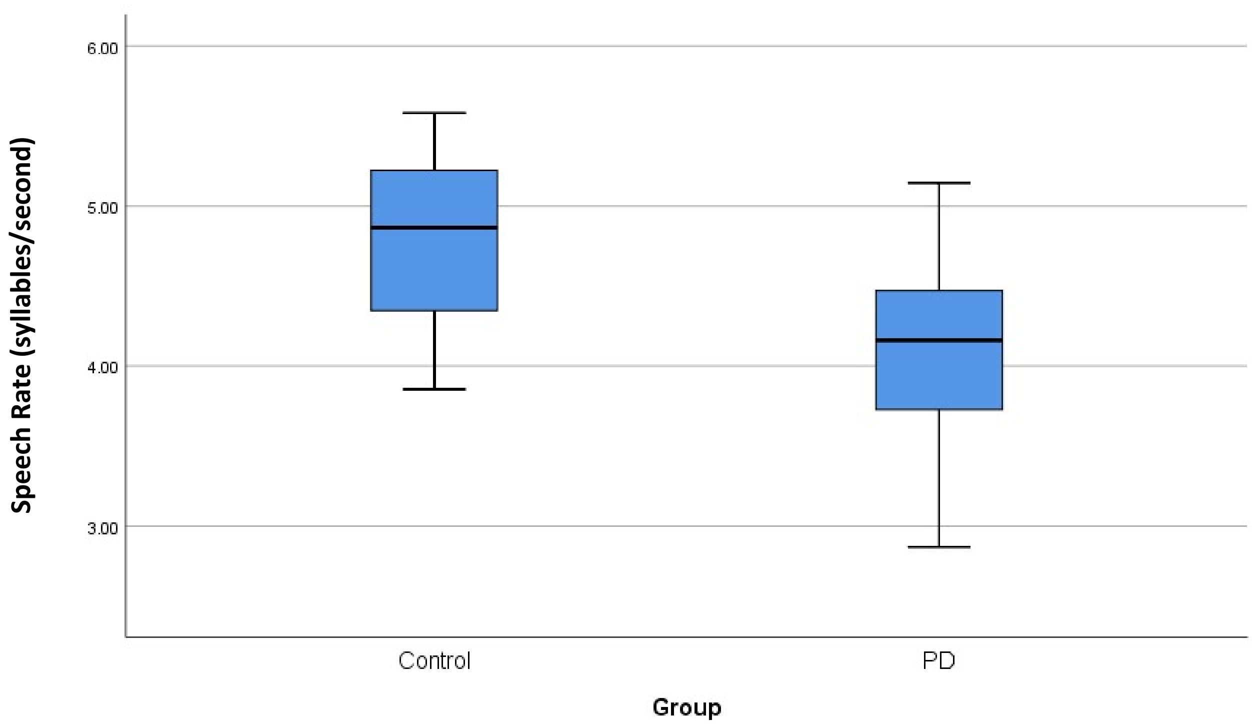
Group data for intensity are illustrated in Figure 3. ANOVA results for intensity were significant for within-subjects effects ($F = 3.262$, $p = .044$), suggesting that the participants greatly varied their intensity as a function of speaking task. However, significance was not shown for between-subjects effects ($F = 3.157$, $p = .084$), so group differences were not revealed. A larger sample size might possibly strengthen these values and display significance. Finally, an interaction effect was not shown for change in intensity between groups and speaking conditions ($F = .149$, $p = .862$). An independent samples t-test revealed group differences on the CAPE-V sentences ($p = 0.049$). These statistics indicate that the experimental group tended to vary intensity between stressed and unstressed syllables more robustly than the control group did during the CAPE-V sentences speaking conditions.

Figure 3. Average group change in intensity among multisyllabic words in CAPE-V sentences



Finally, group data for speech rate are illustrated in Figure 4. ANOVA results for speech rate showed statistical significance for within-subjects effects (F= 15.897, p < 0.000). Group differences were shown in the between-subjects ANOVA (F = 8.320, p = 0.006), suggesting that the PD group spoke at a different rate than their healthy adult counterparts. No interaction effects was shown between speaking condition and group for speech rate (F = 1.308, p = .276). Independent samples t-testing showed that, in the Rainbow passage, subjects with PD tended to speak more slowly than their control counterparts (p < 0.001). These findings are consistent with some bodies of literature and inconsistent with others (Duffy, 2005; Huber & Darling, 2011; Martínez-Sánchez et al., 2015).

Figure 4. Average group speech rate in Rainbow passage speaking condition



Based on the statistical findings, we reject the null hypotheses that frequency and intensity variation across multisyllables are the same for adults with and without PD, and that they speak at the same rate in all three connected speech conditions. Our results are surprising because the literature states that, as Parkinson's disease progresses, speech assumes a more monopitch and monoloudness quality.

Discussion

Prosody is a significant characteristic of one's communication identity and ability. Variation in the pitch, intensity, duration, pausing, and other subtle acoustic factors contributes to the unique character and vibrancy of speech that allows distinct acoustic information to vary between persons. Prosody also acts as a marker of speech input—that is to say, stress and timing manipulation in connected speech provides the listener more specific input regarding speech content and meaning. When examined in combination with articulation and voice, prosody forms a significant component of our understanding of communication decline in Parkinson's disease.

The results of our study suggest that prosody, at least in context with earlier stages of PD, may be of lesser concern than voice and articulation. It may be possible that individuals who have less severe Parkinson's disease and who take medication to alleviate symptoms may either anticipate or be aware of existing shifts in their communication. Perhaps, in order to maximize understanding by the listener, these individuals compensate by over-articulating, over-stressing, and speaking more slowly. Indeed, several individual anecdotes from participants disclosed a transition to a new style of 'comfortable, natural' speech that simply included better enunciation.

Although these data and subsequent speculations serve as piloting information for comparing prosody to other speech changes, several study limitations still exist. Although all study participants exceeded age 40, many in the control group were in their forties, and many in the experimental group were in their sixties and seventies. It is possible that differences in age influenced study results. Additionally, because many possible metrics comprise aspects of prosody, there remains the possibility that our chosen metrics (syllabic stress and speech rate) do not accurately or comprehensively depict prosody in connected speech.

To advance our knowledge of the extent to which prosody in impacted within the overarching picture of communication decline, future directives might include stratifying the comparison groups by gender, age of disease onset or diagnosis, severity of disease progression, or other disease-specific factors. Future iterations of this particular study should utilize a larger sample size to increase effect size and corroborate claims for clinical significance. Additional studies may also evaluate listener perceptions of Parkinsonian speech to isolate information about articulation, voice, and prosody to examine the comparative influences of each on communication identity and intelligibility.

As the prevalence of Parkinson's disease increases rapidly, there becomes a critical need for interventions to maximally preserve quality of life in the absence of a cure. Research that assists clinicians in designing and prioritizing therapy for patients across the scope of daily activities is of utmost importance.

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