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Acoustic Realization of Contrastive Stress in Individuals with Parkinson's Disease

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ACOUSTIC REALIZATION OF CONTRASTIVE STRESS IN INDIVIDUALS WITH
PARKINSON'S DISEASE

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ABSTRACT

This study investigated the acoustic correlates of contrastive stress produced by individuals with

Parkinson's disease (PD) to learn more about their ability to modulate acoustic cues to mark

contrastive stress. Speech materials from 10 individuals with PD and 10 gender- and age-

matched neurologically healthy controls (HC) were recorded and analyzed. The four acoustic

measures (*peak intensity*, *peak F0*, *vowel duration*, and *acoustic vowel space area)* of stressed

and unstressed syllables were compared to determine which acoustic parameters are

preferentially employed by each group to mark contrastive stress. The results indicated that

individuals with PD exhibited significant changes in vowel duration and intensity of

stressed/unstressed words to mark contrastive stress in similar ways to their HC counterparts.

Unlike the HC group, individuals with PD did not demonstrate an expanded vowel space area

(VSA) or employed changes in F0 to mark contrastive stress. Findings on which abilities are

better preserved in the PD population for the purposes of marking contrastive stress add to our

knowledge of prosodic deficits in this dysarthric population and can aid in the planning and

executing of intervention services.

INTRODUCTION

Parkinson's disease (PD) is a neurodegenerative disorder of unknown etiology which is characterized by motor symptoms such as bradykinesia, rigidity, resting tremor, and deficits in postural reflexes (Jankovic, 2008; von Campenhausen et al., 2005). In Europe, its crude incidence has been cited as ranging between 5/100,000 and 26/100,000 while in the United States the Parkinson's Disease Foundation [PDF] (2014) and the National Institute of Neurological Disorders and Stroke [NINDS] (2014) have estimated that 500,000 to 1,000,000 Americans are living with the disease (von Campenhausen et al., 2005). In addition to common and characteristic motor symptoms, as many as 90% of individuals with PD also develop speech disturbances in the domains of voice, articulation, and fluency (Ho, Iansek, Marigliani, Bradshaw, & Gates, 1998; Logemann, Fisher, Boshes, & Blonsky, 1978).

The current study focuses on the characteristics of contrastive stress in the speech of individuals with Parkinson's disease. Parkinson's disease is of particular interest in this study due to its hallmark speech characteristics, which are mostly related to prosodic disturbances (including respiratory-phonatory dysfunctions), such as monoloudness, monopitch, reduced stress, normal-to-fast speech rate, accelerating rate, and breathiness (Darley, Aronson, & Brown, 1975; Duffy, 2013). These hallmark speech characteristics may affect contrastive stress patterns of PD to a greater degree than other diseases. In addition, the speech of individuals with PD is characterized by articulatory imprecision and centralized vowels (Bang, Min, Sohn, & Cho, 2013; Walsha & Smitha, 2011). Prosodic disturbances and articulation deficits are elements of a group of speech symptoms known as hypokinetic dysarthria that is commonly associated with PD, and that results in the perception of the speech of individuals with PD as less intelligible,

more severely affected, and aberrant (e.g., Kempler & Lancker, 2002; Pell, Cheang, & Leonard, 2006).

Research Question and Hypothesis

The overarching goal of this study is to better understand the acoustical realization of contrastive stress in speakers with PD. For this goal, the following two research questions were posed:

1. Can individuals with PD acoustically mark contrastive stress?

2. If so, do speakers with PD mark contrastive stress in the same way as neurologically healthy speakers (HC) do?

I hypothesized that speakers with PD will mark contrastive stress acoustically, but to a lesser degree when compared to healthy speakers. In addition, I hypothesized that they will employ the acoustic parameters being measured (intensity, duration, F0, VSA) differently than speakers in the HC group. For example, the HC group might rely heavily on intensity to signal contrastive stress while the PD group might not rely so heavily on intensity but rely heavily on durational cues instead.

LITERATURE REVIEW

Prosody and Contrastive Stress

Prosody is made up by the patterns of intonation, rhythm, stress, and pauses of a speaker, which can be used to convey information regarding syntax (e.g. question vs. statement), semantic meanings, emotional affect, and speaker identity. Acoustically, prosody is marked by fundamental frequency (F0), intensity contour, and relative timing measures at the phrase level; and by changes in fundamental frequency (F0), intensity, duration, and vowel quality at the syllable level (Hixon, Weismer, & Hoit, 2008). Given the hallmark prosodic characteristics of speakers with PD (monopitch, monoloudness, reduced stress; see Duffy, 2013), they are considered to be impaired across prosodic functions. It has also been noted that the prosodic insufficiencies of speakers with PD are apparent to naïve listeners, which suggests that both linguistic and social competence are affected negatively (Caekebeke, Jennekens-Schinkel, Van der Linden, Buruma, & Roos, 1991; Pell et al., 2006).

Contrastive stress, also known as sentence stress or emphatic stress, is a component of prosody that serves grammatical and semantic roles that can help clarify speaker meaning and aid in listener comprehension (Bolinger, 1961; Lehiste, 1970). For example, in the sentence "she went to the store on FRIDAY" the focus on the word *Friday* signals the importance of that specific word to convey a message. There has been some debate about which acoustic parameters make the most significant contribution to signaling stress with some studies proposing F0 as the primary marker of stress (Morton & Jassem, 1965; O'Shaughnessy, 1979), and others arguing that intensity and duration of stressed segments play an important role in marking stress (Cooper, Eady, & Mueller, 1985; Sluijter & van Heuven, 1996). However, previous literature has proposed the following three as the primary acoustic correlates of

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contrastive stress: (1) F0, which is typically higher in stressed segments; (2) intensity, which is typically louder in stressed segments; and (3) duration, which is typically longer in stressed segments (Bolinger, 1961; Fry, 1955; Lieberman, 1967).

Several studies have also investigated the acoustical characteristics of contrastive stress in dysarthria secondary to traumatic brain injury, cerebral palsy, and stroke, which provided inconsistent findings probably due to the small size of data, and the heterogeneity of speakers with respect to neuropathologies and speech severity (Wang, Kent, Duffy, & Thomas, 2005; Liss & Weismer, 1994; Patel & Campellone, 2009). For example, Wang et al. (2005) suggested that some individuals with dysarthria may present with a preserved ability to mark prosodic contrasts by employing acoustic cues in similar patterns to healthy controls, while others have noted that the acoustic patterns of dysarthric speakers are highly variable (Liss & Weismer, 1994; Patel & Campellone, 2009). Liss and Weismer (1994) reported that dysarthric speakers, like neurologically healthy controls, produced local (e.g. segmental) and non-local (e.g. phrasal) durational effects to distinguish the contrasted word. Furthermore, studies have found that dysarthric speakers used duration, F0, and intensity to mark contrastive stress, but also that dysarthric speakers produced flatter F0 and intensity contours when compared to neurologically healthy controls (Patel & Campellone 2009). Both of these results suggest that duration may be an acoustic parameter that is relatively well preserved for the production of contrastive stress in the dysarthric population.

Three previous acoustic investigations on the subject of contrastive stress in individuals with PD have mostly focused on F0 characteristics and reported mixed results. Darkins, Fromkin, and Benson (1988) found that when asked to produce a set of phrases distinguished by stress such as "green HOUSE" (a house that is green) and "GREENhouse" (a garden structure)

individuals with PD did not exhibit a significant difference across the two stress conditions. However, other studies found that in the same stress task production used in Darkins et al. (1988), the F0 values and patterns of the PD group and the HC group did not differ significantly. Interestingly, the researchers found that individuals with PD were able to perceive and interpret the two different patterns of prosody in the same way as control subjects; however, individuals with PD did not make the same clear distinction that control subjects exhibited through pitch modulation across the different stress conditions (Darkins, Fromkin, & Benson, 1988).

Moreover, other researchers have found that individuals with PD demonstrate differences in F0 and intensity across stress conditions during the production of contrastive stress, but with a reduced magnitude when compared to the differences in healthy speakers (Cheang & Pell, 2007; Tykalova, Rusz, Cmejla, Ruzickova, & Ruzicka, 2014). For example, Cheang and Pell (2007) found that when modulating F0 to mark contrastive stress, individuals with PD produced F0 patterns that were similar to those of HC speakers, but the difference between stressed and unstressed F0 patterns was more pronounced in HC speakers than in speakers with PD. In other words, speakers with PD also raised F0 for stressed words but they did not raise F0 as high as the HC group.

Similarly, intensity has also been speculated as an acoustic variable. Previous studies have reported that individuals with PD modified intensity in the same way as HC speakers, but both stressed and unstressed tokens produced by speakers with PD exhibited significantly lower intensity values (Cheang & Pell, 2007; Tykalova et al., 2014). Only one study included measures of duration in its analysis of contrastive stress in individuals with PD, and that study found no differences in durational trends between the PD group and the speaker group (Tykalova et al., 2014). Nonetheless, it is possible that the effect of stress on duration could have been obscured

by the use of words of varying syllable lengths in the stimuli. Given the convoluted and at times conflicting results presented in previous literature regarding the acoustics of contrastive stress in individuals with PD, the topic merits further investigation focused on analysis of all acoustic parameters associated with contrastive stress. Systematic investigation of contrastive stress including a greater number of acoustic parameters and sentence-level speech stimuli will more effectively address the question of how individuals with PD mark contrastive stress.

The question of how contrastive stress is realized in individuals with PD is theoretically and clinically important, especially given our poor understanding of their ability to modify speech parameters, despite the frequent use of contrastive stress drills in clinical practice. Contrastive stress drills are typically used to increase intelligibility and naturalness by highlighting segments of a stressed word (and thus improving articulation on those segments), and by repeatedly practicing global stress patterns (Duffy, 2013; Liss & Weismer, 1994). When performing contrastive stress drills, the speaker practices scripted responses in which stress patterns vary but segmental information stays the same. Numerous textbooks on clinical practice include information on contrastive stress drills and suggest them as a therapy technique for management of various dysarthrias (Duffy, 2013; Rosenbek & LaPointe, 1985; Yorkston, Beukelman, Strand, & Bell, 1999). However, one study that described an intervention program using contrastive stress drills, vocal efficiency therapy, and verbal repair strategies in individuals with multiple sclerosis (MS) reported an increased ability to mark stress, as well as increased intelligibility and naturalness ratings post-intervention (Hartelius, Wising, & Nord, 1997). Hartelius et al. (1997) proposed that the rationale behind stress patterning intervention is that it implies coordinating exercises involving respiration, phonation, and articulation while highlighting linguistic prominence of certain syllables/words and increasing communicative

awareness, which allows the speaker to focus his energy on the most semantically important segments. However, the effects of contrastive stress intervention alone are still not well understood, especially in the PD population. Therefore, this study seeks to explore both the prosodic modifications employed by speakers with PD to signal contrastive stress as well as their "segmental" (presumably articulatory) modifications, by employing formant frequency measures (Kent & Netsell, 1971).

Acoustic Vowel Space

Acoustic Vowel Space (AVS) or Vowel Space Area (VSA) is a two-dimensional area bounded by the lines connecting plotted values for the first and second formant frequencies (F1 and F2) of the corner vowels: /ɑ/, /æ/, /i/, and /u/ (Hixon, Weismer, & Hoit, 2008). These four vowels represent the limits of vowel articulation, and both perceptually and acoustically they are the most extreme articulatory positions a speaker produces when producing a vowel (Stevens, 2000). The relationship between F1/F2 and tongue placement allows us to make articulatory assumptions based on formant frequency values. F1 is associated with tongue height since a high tongue position results in a low F1 value, while F2 is associated with tongue advancement since an anterior tongue placement results in a high F2 value (Hixon, Weismer, & Hoit, 2008). Given the strong relationship between F1/F2 and the movement and position of oral-facial structures such as the tongue and jaw, VSA can be used as an index of vowel articulation and movement range (Liu et al., 2005). Thus, a smaller acoustic vowel space can indicate a reduced range of tongue movement and result in reduced acoustic vowel contrastivity (Kent & Kim, 2008).

Acoustic vowel space analysis has been extensively used to study aspects of both healthy and disordered speech in children and adults. Prior research has studied changes in acoustic vowel space as a function of speech development (e.g. Flipsen & Lee, 2012), and its relationship

to speech conditions with varying speaking rates and degrees of speech clarity (e.g. Ferguson & Kewley-Port, 2007; Higgins & Hodge, 2001). In fact, the relationship between reduced vowel spaces and lower intelligibility estimates has been well established in the dysarthrias, with studies on the topic encompassing a wide range of etiologies such as cerebral palsy (CP), amyotrophic lateral sclerosis (ALS), traumatic brain injury (TBI), and PD (e.g., Kim, Hasegawa-Johnson, & Perlman, 2011; Liu, Tsao, & Kuhl, 2005; Turner, Tjaden, & Weismer, 1995; Weismer, Jeng, Laures, Kent, & Kent, 2000; Zlegler & Von Cramon, 1983).

Similarly, reduced VSA resulting from the centralization of vowels in individuals with PD has been investigated through acoustic studies that reported that speakers with PD show asymmetric reduction from four corner vowels (/i/ and /u/ are more significantly affected), possibly as a result of more significant articulatory undershoot and deficits in tongue movement for certain vowels compared to others (Kim, 2009; Rusz et al., 2013). Given that stressed words are produced with greater articulatory effort, we would expect them to be more distinct and utilize an expanded VSA; however, very few studies have been published to date detailing how stress condition affects VSA in individuals with PD.

METHODS

Participants

As part of a larger study, speech materials were selected from the archived Louisiana State University (LSU) Motor Speech Database (NIH-NIDCD 012405, 2012-1015). The Parkinson's disease (PD) group selected for this study consisted of 10 individuals (5 male, 5 female). These participants ranged in age from 45 to 74 (M = 60.1, SD = 9), while post-disease-onset times ranged from 1.5 to 13 years (M = 9, SD = 6). All PD participants reported language, hearing, and cognitive skills that were adequate for completing the experimental tasks. The neurologically healthy control (HC) group was also selected from the same archived database, and consisted of 5 male and 5 female participants of comparable age. These participants ranged in age from 38 to 74 (M = 60.5, SD = 9). None of the participants reported any history of speech, language, hearing, or cognition difficulties. Participant information (including intelligibility ratings) is summarized in Appendix A.

Speech Intelligibility Ratings

Speech intelligibility was determined by direct magnitude estimate (DME) perceptual ratings and by a 10-point Equal-Appearing Interval (EAI) rating scale. Five graduate students who were enrolled in a master's program in Speech-Language Pathology at the time of the study performed the DME perceptual ratings. DME is a ratio scaling technique that is used to numerically rate sensory magnitudes of stimuli in fields such as psychophysics, and it has also been frequently used in studies of dysarthria (Schiavetti, 1992). The DME scale included a standard stimulus chosen by the investigator as a good exemplar of midrange intelligibility, and this standard was presented every five utterances (Weismer & Laures, 2002). The standard was

assigned a modulus of 100, and listeners were advised to assign a rating of 200 to those stimuli that were twice as intelligible as the standard, a rating of 50 to those stimuli that were half as intelligible as the standard, and so on. Speech intelligibility was defined to the listeners as the ease with which a speaker could be understood (Weismer & Laures, 2002). Intra-rater reliability was obtained by measuring estimates for 10% of the audio samples a second time, while inter-rater reliability was obtained by calculating the intra-class correlation (ICC) coefficient (Shrout & Fleiss, 1979). The ICC coefficient was 0.81 for the five DME listeners, indicating adequate inter-rater agreement, while the intra-rater reliability ranged from 0.75 to 0.91 (see Appendix B for individual intra-rater reliability coefficients). Both intra-rater and inter-rater levels of reliability were significant, and suggested that the ratings of each utterance were relatively stable across speakers (Kim, Kent, & Weismer, 2011). DME was chosen for intelligibility ratings over the transcription method because it tends to be more sensitive to speech characteristics beyond segment-level articulation, such as prosody (Weismer & Laures, 2002).

Similarly, four graduate students who were enrolled in a master's program in Speech-Language Pathology performed the EAI ratings. The EAI method, another commonly used scaling method in studies of dysarthria, requires listeners to assign each speech sample a number along a predetermined partitioned continuum (Schiavetti, 1992). A 10-point scale was used for the EAI ratings, with number 1 marked as "least intelligible" and number 10 marked as "most intelligible" on every page. Inter-rater and intra-rater reliability of EAI ratings were calculated following the same procedure that was used to obtain reliability of DME ratings. The ICC coefficient was 0.95 for the four EAI listeners, indicating high agreement, while intra-rater reliability ranged from 0.74 to 0.92 (see Appendix B for individual intra-rater reliability coefficients). Both the intra-rater and inter-rater levels of reliability are considered satisfactory

for this type of study (Eadie & Doyle, 2002). Some researchers have proposed that DME may be more appropriate for rating speech intelligibility due to the prothetic nature of speech intelligibility (when listeners try to partition it in equal intervals they subdivide the lower end into smaller intervals than the upper end), and because more statistical operations are allowed by DME due to its ratio level of measurement, instead of traditional binary or categorical measurements (Schiavetti, 1992). However, partly due to its relative nature (in other words, the DME values are not directly comparable across studies of which modulus are somewhat arbitrarily selected by the researchers), both were included in this study. DME and EAI ratings suggested that the speakers with PD who participated in this study were in the mild-moderate severity category of speech intelligibility.

Recording Procedures

Audio recordings for each participant were obtained individually in a single 30-45 minute session in a quiet testing room (either a quiet room in their homes or in a sound-treated booth). No time limits were imposed during the recordings, and participants were allowed to take breaks whenever they desired it. Speech samples were collected either with a Perception 120 (AKG) microphone directly transferred to a Dell Optiplex 750 computer or a professional portable recording device (TASCAM DR-40). Speech recordings were made with a sampling rate of 22.1 kHz and 16-bit quantization. The examiner explained she would be producing the same sentence but a different word would be emphasized each time and asked participants to repeat each sentence 3 times, exactly as the examiner (see Table 1). The sentence, "put these two back", was made up of 4 monosyllabic words, which provides 4 different stress conditions as well as 3 corner vowels (/i/, / æ /, /u/) for analysis. This sentence has been widely used in clinic and research and takes advantage of monosyllabic words that minimize the effects of linguistic

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complexity and vital capacity deficits that characterize PD. The examiner presented stress

conditions in the same order for all participants. Since participants were asked to repeat the

sentence for each stress condition 3 times, a total of 240 utterances were collected for analysis

(20 speakers* 3 repetitions * 4 stressed conditions).

Table 1. Contrastive Stress Production Protocol

Stress Condition	Sentence
1	PUT these two back
2	put THESE two back
3	put these TWO back
4	put these two BACK

Note. Capitalized words were produced with emphasis.

The study was approved by the Institutional Review Board (IRB) at Louisiana State University

and all participants provided written, informed consent for the speaking tasks and recording

procedures.

Acoustic Measurements

Using speech analysis software TF32 (Milenkovic, 2005), acoustic measurements were

made of *peak fundamental frequency* (peak F0), *intensity* (peak intensity), *vowel duration,* and

formant patterns (F1 and F2) for all word tokens in both stressed and unstressed conditions. Peak

F0 and intensity were measured by visualizing pitch and intensity contours and recording the

highest point of F0 and intensity for each vowel. Vowel duration and formant frequency patterns

(F1 and F2) were examined from the waveform and spectrogram. Vowel duration was measured

from the first glottal pulse of the vowel to the onset of the following consonant or silent segment

(Hillenbrand, Getty, Clark, & Wheeler, 1995). First and second formant frequencies were

measured at the temporal midpoint of the vowel following conventional criteria (Peterson &

Barney, 1952). Tracking errors observed for formant trajectories, or pitch contours (often due to poor voice quality) were manually modified using the interactive editor in TF32. There is a well-known effect of word position at the phrase level that affects fundamental frequency, intensity, and duration. For example, in declarative sentences peak F0 occurs near the beginning of the phrase and thereafter F0 gradually declines to its lowest point at the end of the phrase (Lehiste, 1970). Similarly, there is a phrase-final lengthening effect that aids in marking syntactic boundaries and accounts for longer vowel durations at the end of phrases (see Klatt, 1976). The present analysis was carefully performed in consideration of these potential effects of position of the target syllable within the sentence.

Finally, two sets of triangular vowel spaces (stressed and unstressed) were calculated for each group (PD and HC) by averaging F1 and F2 values of vowels /i/, / u/, and /æ/ and using the following formula modified from Liu et al. (2005):

Vowel triangle area = ABS $\{[F1i *(F2æ - F2u) + F1æ *(F2u - F2i) + F1u *(F2i - F2æ)] /2\}$

Where "ABS" is the absolute value, "F1i" refers to the F1 value for /i/, "F2u" refers to the F2 value of /u/, and so on. Although /ɑ/ is typically used to calculate triangular vowel space, /æ/ will be used in this study as an alternative low vowel given that it was the low vowel present in the speech stimuli. In order to analyze formant frequency data of both men and women together for each speaker group, F1 and F2 values will be normalized using the Bark Difference Metric, following conventional procedures (Syrdal & Gopal, 1986). Reliability of acoustic measurements was assessed by re-measuring a randomly selected sample comprising 10% of total data 3 weeks after the initial measurements. The intra-rater reliability coefficient was 99%, and the inter-rater reliability coefficient was 96%.

To examine the acoustic correlates of contrastive stress in the productions of individuals with and without PD, paired t-tests were conducted for each dependent variable. Data for males and females were pooled for the analysis of duration, intensity, VSA (formant frequency values were normalized using Bark metric), and F0 (stressed/unstressed differences between the two speaker groups were analyzed in semitones). Within speaker group comparisons of F0 (in Hz) and VSA (in Hz²) were conducted by separating the male and female groups. Similarly, the overall fundamental frequency (in Hz) of speaker groups was compared separately for males and females. Findings and interpretations for each acoustic parameter examined in this study are listed below.

F0 Peak

To determine whether the PD and HC groups made similar changes to the F0 peak between stressed/unstressed conditions, a paired t-test comparing the difference in semitones across the two stress conditions was performed. A statistically significant difference was found between the two participant groups. The mean stressed/unstressed difference in semitones for the PD group was 1.7, and for the HC group it was 3.7 (Table 3). This finding suggests the PD group and the HC group did not make similar changes to the F0 peak of stressed and unstressed words. Furthermore, it suggests that speakers with PD did not use fundamental frequency as an acoustic marker of contrastive stress.
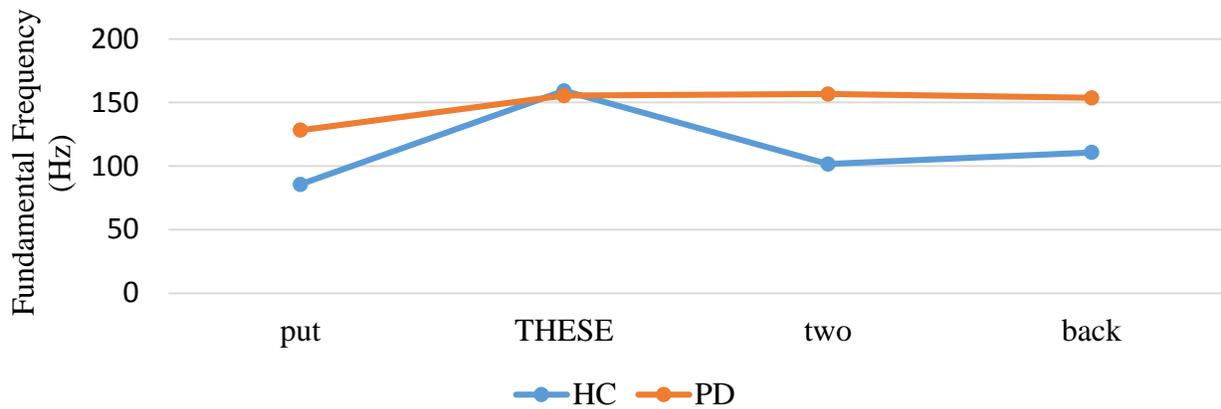
Figure 1. Peak F0 for males when the word "these" was emphasized.
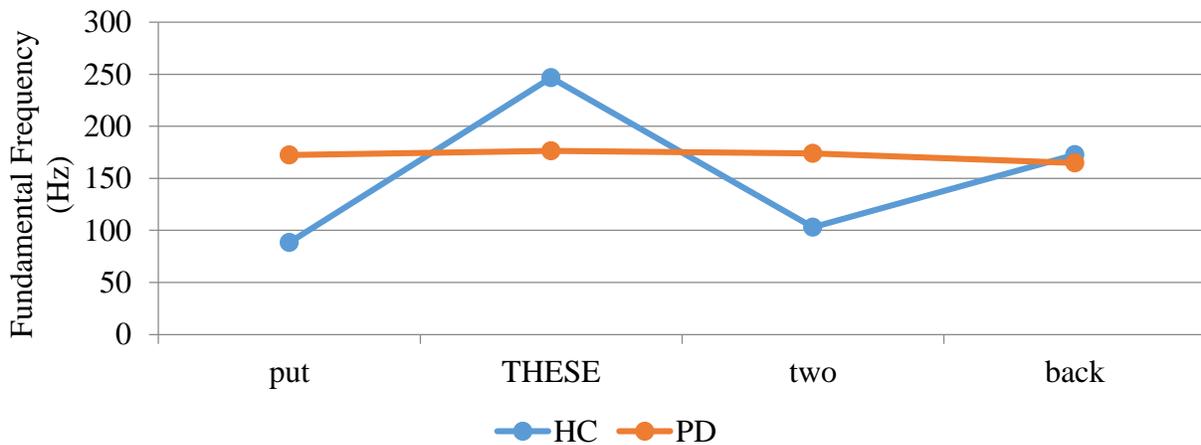
Figure 2. Peak F0 for females when the word "these" was emphasized.

Figures 1 and 2 illustrate the average fundamental frequencies of the two speaker groups when the second word of the phrase was emphasized. Both male and female fundamental frequency patterns were flat and did not follow the same pattern exhibited by the HC group (speakers with PD did not increase F0 for the stressed word). In addition, the overall fundamental frequency of PD males was higher than that of their HC counterparts (Table 3).

Intensity

The paired t-test revealed no significant difference between the stressed/unstressed intensity differences in dB of the HC and the PD groups. The mean stressed/unstressed intensity difference for the HC group was 4.29 dB, while for the PD group it was 4.13 dB (Table 2). This finding suggests that the PD group successfully contrasted stressed and unstressed words using changes in intensity in a similar way to the HC group. However, the overall intensity mean of the PD group was lower for both the stressed (-19.4 dB) and unstressed (-23.5 dB) conditions compared to the overall mean intensity of the HC group for stressed (-15.3) and unstressed conditions (-19.6).

Figure 3. Peak intensity when the word "these" was emphasized.
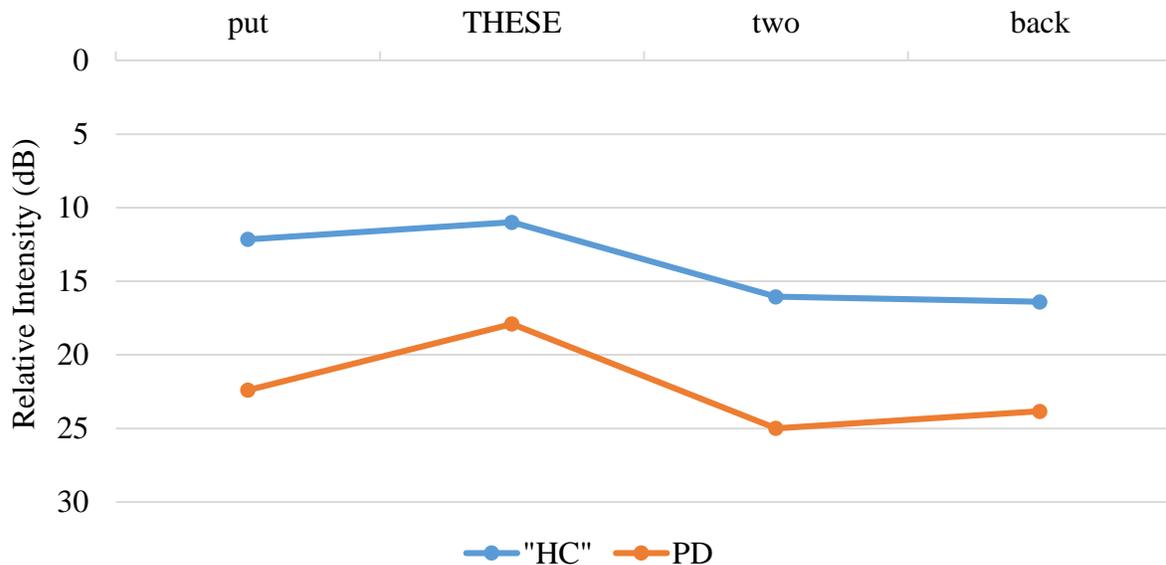
For the utterance illustrated in Figure 3, the overall intensity was lower for the PD group than the HC group (M = 12.95 dB for PD group, M = 21.48 dB for HC group). In addition, intensity patterns for both speaker groups were remarkably similar, with a slight rise in intensity for the stressed word and a decline of intensity for the remainder of the sentence.

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Duration

The paired t-test revealed no significant difference between the stressed/unstressed durational differences of the HC and the PD groups. The mean stressed/unstressed durational difference for the HC group was 52.1 ms, while for the PD group it was 39.1 ms (Table 2). This finding suggests that the PD group successfully contrasted stressed and unstressed words using changes in duration in a similar way to the HC group. The mean vowel duration difference across stress conditions for the PD group was 39.1 ms, a nonsignificantly shorter durational difference than that of the HC group (52.08 ms).
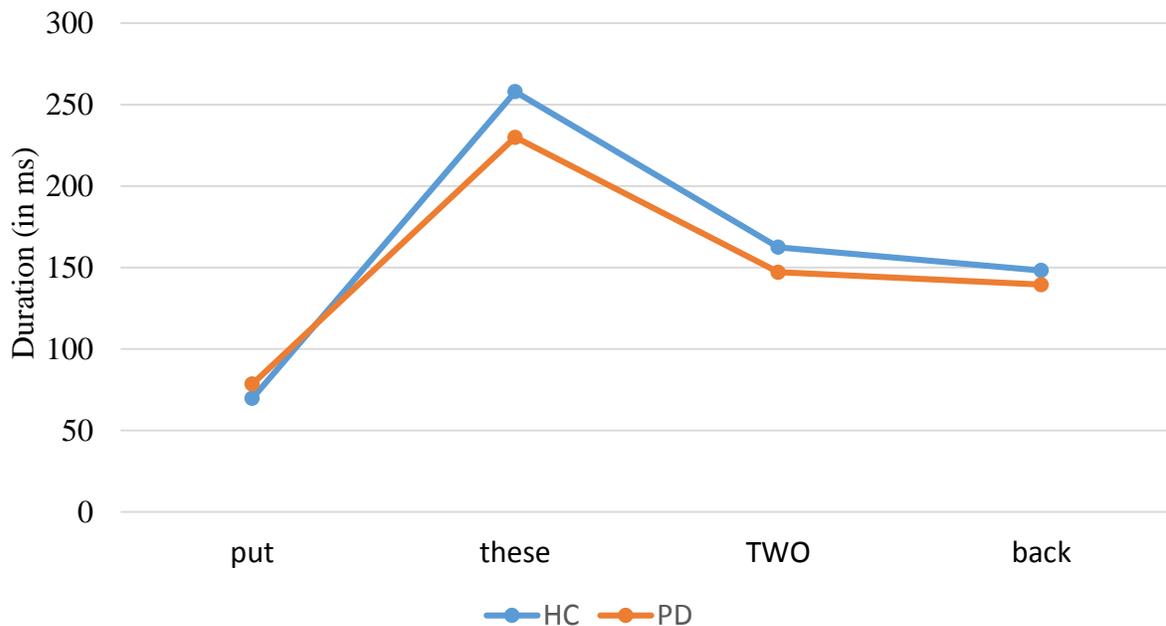
Figure 4. Vowel duration when the word "two" was emphasized.

Vowel duration patterns of both groups are also notably similar, with a sharp rise in duration for the stressed word and a slight rise in duration in the phrase-final position, suggesting duration may be the best preserved acoustic parameter for marking contrastive stress in individuals with PD. Although modulation of vowel duration appears to be better preserved than the ability to modulate other acoustic cues to mark contrastive stress for speakers with PD, it was

still slightly reduced when compared to controls speakers (Table 3). This may be due to the fast speech rate that is distinctive in individuals with PD.

Vowel Space Area

The paired t-test revealed a statistically significant difference between the stressed/unstressed VSA of the HC group (2.17 in Bark, see Table 2). On the other hand, the stressed/unstressed VSA difference was not significant for the PD group (0.75 in Bark). This finding suggests that the PD group did not employ changes in VSA to acoustically mark contrastive stress. Both the mean stressed VSA (5.6 in Bark) and the mean unstressed VSA (3.5 in Bark) were larger for the HC group when compared to the mean stressed VSA (2.9 in Bark) and the mean unstressed VSA (2.0 in Bark) of the PD group, which suggests an overall reduction in the VSA of speakers with PD across stress conditions.
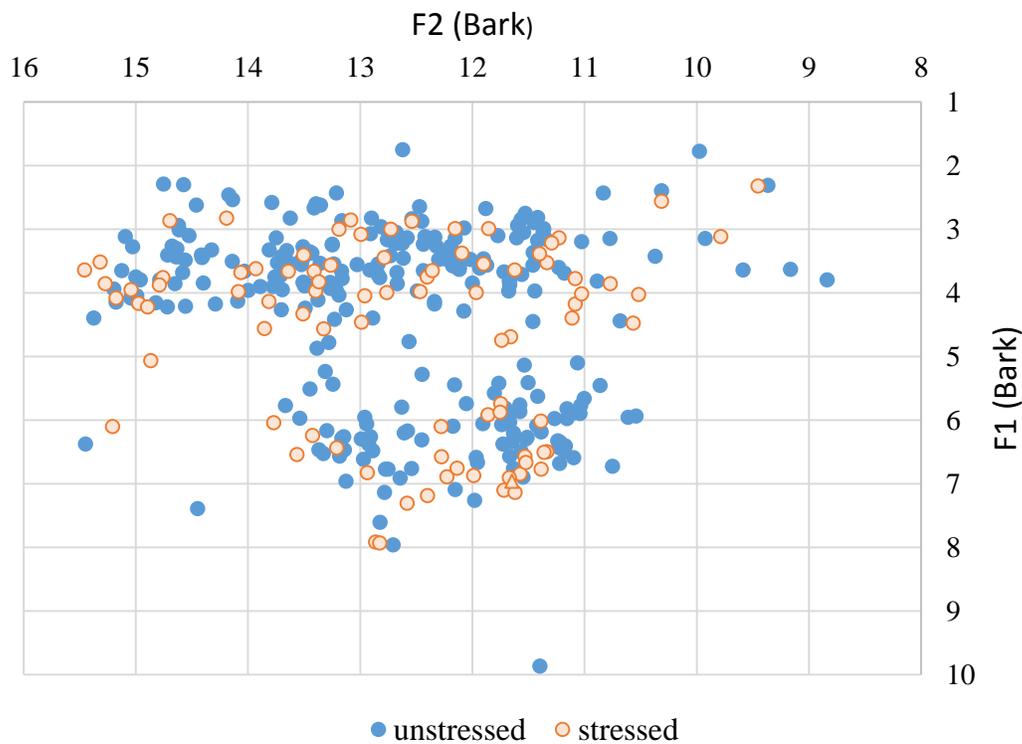
Figure 5. Stressed and unstressed triangular VSA of the PD group.
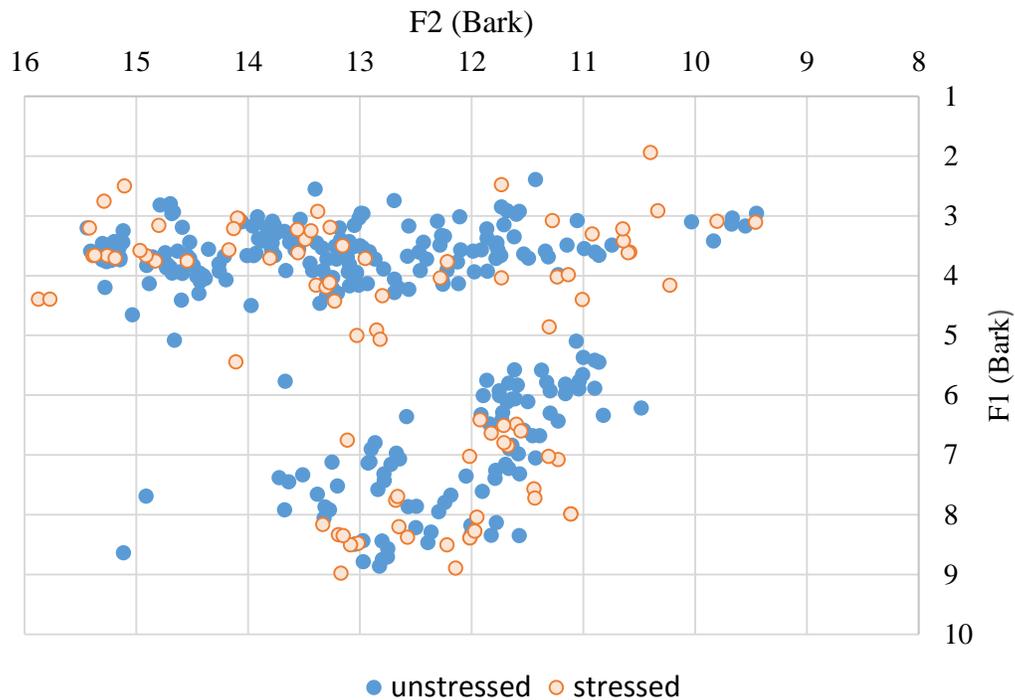
Figure 6. Stressed and unstressed triangular VSA of the HC group.

Figures 5 and 6 depict all corner vowel productions measured in this study. The VSA of the PD group is smaller than that of the HC group for both stressed and unstressed conditions, with numerous productions in the middle area of the triangle and some outliers scattered in the periphery of the VSA. The VSA of the HC group is visibly more defined and exhibits fewer outliers, while presenting a starker contrast between the stress and unstressed conditions than that of the PD group.

Summary of Statistical Results

The following table (Table 2) summarizes statistical information for all acoustic parameters discussed in this section. The HC group utilized all four acoustic parameters to differentiate stressed and unstressed conditions. On the other hand, the PD group only utilized

two of those same four acoustic parameters to differentiate stressed and unstressed conditions (duration and intensity).

Table 2. Summary of Statistical Results: Comparison between Stressed and Unstressed Syllables by Participant Group (Durational and intensity differences are bolded because they were statistically significant parameters for the PD group).

	PD			HC		
	Mean	SD	P-Value	Mean	SD	P-Value
Durational difference (in ms)	39.104	45.098	0.0047*	52.081	48.105	0.0007*
Intensity difference (in dB)	4.131	2.639	<0.001*	4.293	2.644	0.007*
F0 peak difference for females (in Hz)	16.611	20.751	NS(0.114)	58.643	51.218	0.0077*
F0 peak difference for males (in Hz)	18.322	21.857	NS(0.220)	40.178	44.979	0.0454*
VSA difference for females (in Hz²)	54597	50307	NS(0.072)	81592	35242	0.0066*
VSA difference for males (in Hz²)	22778	38725	NS(0.259)	98317	27400	0.001*
VSA difference (in Bark)	0.829	0.754	NS(0.079)	2.17	1.30	0.0236*

NS: Not significant

The following table (Table 3) summarizes statistical information relevant to the comparison of the overall speech characteristics of the two speaker groups. Mean duration, mean intensity, mean F0, and mean VSA were obtained by pooling all stress conditions.

Table 3. Summary of Statistical Results: Overall Speech Characteristics of Parkinson's Disease Compared to Healthy Controls

	PD mean	Direction	HC mean	P-value
Mean Duration (in ms)	162.9	<	184.6	NS (0.09)
Duration difference (in ms)	39.104	<	52.081	NS (0.427)
Mean Intensity (in dB)	12.95	<	21.48	<0.0001*
Intensity difference (in dB)	4.131	<	4.293	NS (0.785)
F0 difference (in semitones)	1.747	<	3.715	0.0008*
Mean F0 males (in Hz)	185.1	<	149.759	0.0060*
Mean F0 females (in Hz)	179.6	>	157.7	NS(0.088)
Mean VSA (in Bark)	2.47	<	4.55	0.000497*

NS: Not significant

DISCUSSION

This study aimed to determine whether individuals with PD use certain acoustic parameters to mark contrastive stress in the same way that healthy speakers do. This question was particularly relevant to the PD population given their prosodic disturbances and patterns of reduced stress. Unlike previous studies that mostly focused on conventional prosodic cues such as duration, F0, and intensity, this study also explored formant pattern of vowels (represented by VSA) in order to evaluate the contribution of segmental level of articulation to realization of contrastive stress.

Comparison Between the HC and PD Groups

Statistical analysis revealed that the HC group utilized longer duration, higher F0, louder intensity, and an expanded VSA to mark contrastive stress. These findings are consistent with available literature on contrastive stress by healthy individuals (Hixon et al., 2008; Lehiste, 1970). Our results also indicate that despite exhibiting some abnormal patterns of speech, individuals with PD used some (but not all) of the same acoustic parameters that healthy speakers used to mark contrastive stress. Specifically, individuals with PD employed durational differences and intensity differences, but not differences in F0 or VSA to contrast stressed and unstressed conditions. In addition, individuals with PD did not modulate acoustic parameters to the same degree as healthy individuals, and there were slight differences between the two groups even for the parameters (duration and intensity) that individuals with PD utilized successfully when marking contrastive stress. Although the differences in the magnitude of duration and intensity modulation were not statistically significant, they showed a tendency of less pronounced changes in the PD group. In fact, the extent of the differences between the stressed and unstressed conditions for all acoustic variables in the study was smaller for the productions

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of individuals with PD than those of healthy individuals, suggesting that although the PD group can successfully modulate some acoustic parameters during the production of contrastive stress, they were less effective than their HC counterparts in the use of all acoustic parameters studied.

Overall Acoustic Characteristics and Duration in Individuals with PD

The results of this study are consistent with previous work (Bang et al., 2013; Cheang & Pell, 2007; Holmes, Oates, Phyland, & Hughes, 2000; Peterson & Barney, 1952; Tykalova et al., 2014) in that individuals with PD exhibited an overall intensity reduction, reduced acoustic vowel spaces, shorter word durations, flatter F0 contours, higher overall F0 for males, and similar within-sentence modulation patterns for intensity and duration. Although there have only been two studies that have investigated duration in contrastive stress in the PD population (Cheang & Pell, 2007; Tykalova et al., 2014), the results of the current study were in agreement with these studies despite differences in the length of the speech stimuli and the nature of the production task. Perhaps manipulation of durational cues is one of the most accessible prosodic mechanisms across the dysarthric population, given that changes in duration were also shown to be exploited as a prosodic marker in one study of individuals with dysarthria secondary to CP (Patel & Campellone, 2009).

F0 Differences in Individuals with PD

The evidence on whether F0 is utilized as a marker of contrastive stress by individuals with PD has been conflicting (Cheang & Pell, 2007; Darkins et al., 1988; Tykalova et al., 2014), and because of this F0 appears to have the most complex and hard-to-understand relationship with the realization of contrastive stress in individuals with PD out of all the acoustic parameters analyzed in this study. The findings of this study support the body of research that suggests that

F0 modulation is not successfully utilized by individuals with PD when marking contrastive stress (Cheang & Pell, 2007). It could also be possible that some of the discrepancies observed in the literature of F0 regarding the productions of contrastive stress by individuals with PD might be due to differences in methodologies, since researchers have measured different parameters such as F0 range, maximum F0, mean F0, and overall pitch contours.

Intensity Differences in Individuals with PD

In opposition to previous work (Cheang & Pell, 2007) but in agreement with other published research (Tykalova et al., 2014), this study found that individuals with PD utilize subtle differences in intensity within a sentence to mark contrastive stress. This finding is surprising given the prevalence of an overall intensity reduction in the speech of individuals with PD. However, it must be noted that the mechanism for making small changes in intensity from one word to the next is not the same as the mechanism for maintaining an intensity level over an entire utterance. Therefore, it is possible that speakers could maintain the ability to make small changes in intensity even if the overall intensity of their utterances were reduced. It is also possible that individuals with PD who participated in this study successfully marked contrastive stress in part because they were following a clinician model, rather than speaking spontaneously. Having the clinician model the changes and being explicitly told they would be stressing different words in sentences might have facilitated intensity modulation for participants with PD.

Clinical Implications

Since the ability to make changes in duration and intensity appeared to be relatively well preserved in individuals with PD for the purposes of marking contrastive stress, they could be targeted during therapy to maximize residual capacities. Conversely, therapy could target

expanded acoustic vowel spaces or F0 modulation if the goal of therapy were remediation of inadequate areas.

Limitations and Future Directions

This study was not without its limitations and future studies should include participants from all severity ranges in order to further our understanding of this topic. In addition, it would be beneficial to explore the relationship between acoustic measurements and listeners' perceptual aspects of PD speech and with the perceptual distinctiveness of stressed syllables within utterances (including speech intelligibility) in order to gain an understanding of how the realization of these acoustic parameters affects daily communication in the PD population. Future research should continue to explore other acoustic parameters that may be acting in conjunction with intensity, duration, and pitch. Pauses are a parameter that has been explored in other studies of contrastive stress with etiologies besides PD (e.g. Patel & Campellone, 2009) and could be relevant to the PD population given their preserved ability to manipulate vowel durations. Finally, given the wide variability of speech deficits within the PD population and also the variability implicit even across neurologically healthy speakers, an in-depth study examining the individual patterns of both speaker groups would shed light on individual differences that are important to consider when delivering individualized speech therapy.

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Participant	Gender	Age	Onset of PD	DME	EAI
PD1	F	45	13 years	62	2.6
PD2	F	58	6 years	74	3.4
PD3	M	55	24 years	71	3.4
PD4	M	74	8 years	76	3.9
PD5	M	74	4 years	83	5.3
PD6	F	68	6 years	96	3.9
PD7	F	69	13 years	85	4
PD8	F	68	1.5 years	96	5.8
PD9	M	70	4 years	95	6.2
PD10	M	60	5 years	106	6.4
HC1	M	53	---	90	4.1
HC2	M	69	---	119	6.5
HC3	M	72	---	109	6.8
HC4	M	62	---	150	8.1
HC5	F	72	---	124	7.3
HC6	F	62	---	156	9.1
HC7	M	49	---	121	7.2
HC8	F	54	---	138	8.5
HC9	F	62	---	181	9.8
HC10	F	38	---	182	9.9

APPENDIX B

Listener #	DME Reliability	Listener #	EAI Reliability
1	0.87	1	0.86
2	0.78	2	0.88
3	0.75	3	0.92
4	0.91	4	0.75
5	0.78		
Mean	0.82	**Mean**	0.85

VITA

Ana Maria Gaviria was born and raised in Barranquilla, Colombia. She graduated from

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