THE EFFECTS OF SPEECH TASKS ON THE PROSODY OF PEOPLE WITH PARKINSON DISEASE

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For all those making their voices heard and those who support them

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TABLE OF CONTENTS

LIST OF TABLES 7
ABSTRACT 8
INTRODUCTION 9
- Prosody and Stress Patterns in Standard American English 9
- Overall Profile of Prosodic Insufficiency in Parkinson Disease 11
- Changes to Lexical Stress in Parkinson Disease 13
- Task Differences in Assessing Dysprosody 14
- Associated Cognitive Changes in Parkinson Disease 18
- Naturalistic Assessment of Prosody in Parkinson Disease 19
- Hypotheses 20

METHODS 21
- Participants 21
- Equipment 22
- Stimulus 23
- Acoustic Measurements and Derived Values 25
- Correcting Pitch-Tracking Errors for f_0 Measures 26
- Correcting Formant-Tracking Errors for F1 and F2 Measures 29

RESULTS 31
- Duration of Vowel 31
- Mean Pitch of Vowel 32
- Mean Intensity of Vowel 32
- Pairwise Variability Index of Duration 33
- Pairwise Variability Index of Mean Pitch 33
- Pairwise Variability Index of Mean Intensity 34
- Bark Scale F1 (20%, 50%, and 80%) 34
- Bark Scale F2 20% 35
- Bark Scale F2 50% 36
- Bark Scale F2 80% 37
- Euclidean Distance of F1 and F2 (first half of vowel) 38

Euclidean Distance of F1 and F2 (second half of vowel) 38

DISCUSSION 40

The Effects of Parkinson Disease on the Marking of Lexical Stress 40

The Effects of Task on the Marking of Lexical Stress 41

Differences in Marking of Lexical Stress for Trochees and Iambs 42

The Significance of Formants in Lexical Stress 43

Limitations and Future Directions 45

Lexical Control of Positional Location in Phrase 45

Lip and Jaw Positioning for Consonants and Vowels 45

Mean Pitch and Mean Intensity vs Min/Max 46

Vocal Fry 46

Formant 3 (and Higher) 47

Conclusions 47

APPENDICES

APPENDIX A. PICTURE LISTING TASK 60

APPENDIX B. MAP TASK: STREETS 61

APPENDIX C. MAP TASK: ZOO 62

APPENDIX D: VOWEL QUADRILATERALS BY GENDER AND TASK 63

REFERENCES 64

LIST OF TABLES

Table 1: Overall Profile of Prosodic Insufficiency in Parkinson Disease 12
Table 2: Changes to Prosody in Parkinson Disease (versus controls): Differentiation between Stressed and Unstressed Segments by Task and Stimulus.. 15
Table 3: Participant Demographic Information 23
Table 4: Stimulus Words to be Analyzed by Task 30
Table 5: Main Effects of Group: Means (standard error in parentheses) 48
Table 6: Main Effects of Task: Means (standard error in parentheses).. 49
Table 7: Main Effects of Syllable Number: Means (standard error in parentheses) 50
Table 8: Main Effects of Stress Pattern: Means (standard error in parentheses).......................... 51
Table 9: Group x Task Interaction Effects: Means (standard error in parentheses)..................... 52
Table 10: Group x Syllable Number Interaction Effects: Means (standard error in parentheses) 53
Table 11: Group x Stress Pattern Interaction Effects: Means (standard error in parentheses)..... 54
Table 12: Task x Syllable Number Interaction Effects: Means (standard error in parentheses).. 55
Table 13: Task x Stress Pattern Interaction Effects: Means (standard error in parentheses) 56
Table 14: Syllable Number x Stress Pattern Interaction Effects: Means (standard error in parentheses).. 57
Table 15: Task x Syllable Number x Stress Pattern Interaction Effects: Means (standard error in parentheses).. 58

ABSTRACT

One of the key features of the hypokinetic dysarthria associated with Parkinson disease is dysprosody. While there has been ample research into the global characterization of speech in Parkinson disease, little is known about how people with Parkinson disease mark lexical stress. This study aimed to determine how people with Parkinson disease modulate pitch, intensity, duration, and vowel space to differentiate between two common lexical stress patterns in English: trochees (strong-weak pattern) and iambs (weak-strong pattern), in two syllable words. Twelve participants with mild to moderate idiopathic Parkinson disease and twelve age- and sex-matched controls completed a series of speech tasks designed to elicit token words of interest in prosodically-relevant speech tasks (picture identification (in isolation and lists) and giving directions (spontaneous speech). Results revealed that people with Parkinson disease produced a higher overall pitch and a smaller vowel space as compared to controls, though most lexical marking features were not significantly different. Importantly, the elicitation task had a significant effect on most dependent measures. Although lexical stress is not significantly impacted by Parkinson disease, we recommend that future research and clinical practice focus more on the use of spontaneous speech tasks rather than isolated words or lists of words due to the differences in the marking of lexical stress in the latter tasks, making them less useful as ecologically-valid assessments of prosody in everyday communication.

INTRODUCTION

During interviews with 37 people with Parkinson disease (PD), Miller, Noble, Jones, and Burns (2006) asked participants about their major concerns regarding their communication. Three major themes emerged: the increased effort to communicate, difficulty interacting with others, and a diminished view of the self. One participant qualified this by saying "I never know when I start to talk…what tone or pitch is going to come out." Another participant said, "People just keep staring at you when you cannot get your words out…so I just avoid the people."

The hypokinetic dysarthria associated with PD is debilitating on multiple levels, and it has been well-studied in terms of discerning key symptoms and devising treatment protocols. While there is widespread agreement that prosodic impairment is one of the key speech symptoms of hypokinetic dysarthria associated with PD, findings are mixed about the exact nature and cause of the dysprosody, and therefore how to treat it. To address the social-communication needs of people with PD, it is important to characterize what they are doing in prosodic tasks to highlight what remains challenging.

Prosody and Stress Patterns in Standard American English

Prosody serves many linguistic and extralinguistic functions in Standard American English, including but not limited to lexical stress (syllable differentiation in words), contrastive stress (emphasizing a specific word in a sentence), sentence mode differentiation (declarative vs interrogative), emotional expression, and turn-taking. Prosody further serves as a cue to resolve semantic ambiguities in connected speech, usually coinciding with morphosyntactic cues. All these functions involve manipulation of the vocal tract, resulting acoustically in modulations of fundamental frequency (f_0), intensity, duration, and formant structure. Impairments in one prosodic function do not necessarily mean that other prosodic functions will be similarly affected, as many speech-language functions dissociate. Careful task construction is needed to isolate these functions.

The prototypical pattern of stress in healthy speakers of Standard American English is to elevate f_0, increase intensity, increase duration, and open the mouth wider for the vocalic segment to be emphasized (Fry, 1955; Fry, 1958; Lieberman, 1960). Stressed syllables are usually marked using these acoustic cues with non-emphasized vocalic segments being reduced in each of these aspects. While earlier researchers attempted to establish a hierarchy between these cues, most now agree that there is not a single dominant acoustic cue. Instead, cue trading is common for both healthy speakers (Lieberman, 1960) and speakers with dysarthria (Patel & Campellone, 2009). Cue trading is a useful strategy because while listeners can use redundant cues additively to recognize words more quickly (Nakatani & Aston, 1978), not all cues are reliably used, even by healthy speakers. Further, while adult speakers of Standard American English mark differences between the syllables of both trochees (strong-weak) and iambs (weak-strong), these modulations tend to be greater in iambs than in trochees (Goffman & Malin, 1999).

English listeners rely on lexical stress cues in some listening situations, such as differentiating minimally contrastive bisyllabic pairs in connected speech (Gordon-Salant, Yeni-Komshian, Pickett, & Fitzgibbons, 2016) or rapidly recognizing individual words with differential stress but identical segmental content (Jesse, Poellmann, & Kong, 2017). There is also evidence that these listeners may use different cues depending on whether they are listening to single-word productions (Cutler & Clifton, 1984) or connected speech, especially depending on where the stressed word is in a sentence (Nakatani & Aston, 1978). Finally, listeners may be more attuned to one or more cues depending on factors including the size of their vocabulary

(McAuliffe, Gibson, Kerr, Anderson, & LaShell, 2013), their communication partner's accent (Kondaurova & Francis, 2008), and the amount of noise in the communication environment (Borrie, Baese-Berk, Van Engen, & Bent, 2017). This makes it important for any speaker to have a flexible command of different cues.

The core features of prosody (f_0, amplitude, duration, and articulatory space) are often significantly affected in people with PD. This can lead to difficulties with lexical stress marking, increasing the effort required to create meaningful stress differences and making it harder for a communication partner to understand a person with PD's speech.

Overall Profile of Prosodic Insufficiency in Parkinson Disease

The overall profile of prosodic insufficiency for people with PD has remained consistent since the initial description of the cluster by Darley, Aronson, and Brown (1969) (Table 1). People with PD produce monopitch speech, characterized by reduced f_0 variation (Skodda, Rinsche, & Schlegel, 2009; Rusz, Cmejla, Ruzickova, & Ruzicka, 2011), reduced f_0 range (Rusz et al, 2011; Tykalova, Rusz, Cmejla, Ruzickova, & Ruzicka, 2014), and flat (Tykalova et al., 2014) or syntactically inappropriate (MacPherson, Huber, & Snow, 2011) f_0 contours. People with PD also tend to have monoloudness consistent with hypophonia and characterized by reduced intensity, reduced intensity range (Tykalova et al., 2014), and reduced intensity variation (Rusz et al., 2011). People with PD have variable rate abnormalities characterized by short rushes of speech in addition to slowed rates (and often shorter utterances) (Kent & Rosenbek, 1982; Bunton & Keintz, 2008). While some researchers have found shorter vowel durations (Tykalova et al., 2014), others report longer vowel durations (Watson & Munson, 2008). Finally, people with PD tend to present with a reduced articulatory-acoustic vowel space (Watson &

Munson, 2008; Bang, Min, Sohn, & Cho, 2013; Whitfield & Goberman, 2014), contributing both to more neutralized vowels and imprecise consonants. These symptoms tend to worsen in later stages of the disease (Holmes, Oates, Phyland, & Hughes, 2000).

Table 1: Overall Profile of Prosodic Insufficiency in Parkinson Disease

Monopitch	Monoloudness
• Reduced f_0 variation • Reduced f_0 range • Flat or syntactically inappropriate f_0 contour	• Reduced intensity • Reduced intensity variation • Reduced intensity range
Rate Abnormalities	Reduced Articulatory-Acoustic Vowel Space
• Short rushes of speech • Slowed rate concomitant with word-finding difficulties • Variable vowel duration	• Reduced stress differentiation • Imprecise consonants

Some results related to prosody are partially contradictory to these general findings. For instance, Ma, Schneider, Hoffman, & Storch (2015) examined many of the classic symptoms of PD in German speakers during both sentence reading and spontaneous speech, and found higher average intensity than healthy controls, along with *no* significant differences between groups for f_0 average and variability. They also found very few significant differences in how people with PD used prosodic cues between different tasks, with healthy controls producing a higher f_0 envelope in the sentence reading task than in spontaneous speech. Similarly, Tykalova et al. (2014) reported that the only significant difference between people with PD and healthy controls in f_0 is f_0 range.

The consensus is that Parkinson disease can manifest with symptoms affecting a person's ability to modulate pitch, intensity, duration, and the articulatory vowel space. These general speech characteristics of PD could have a significant impact on a person with PD's ability to use prosody for some, if not all, prosodic functions. However, there have been limited studies about how people with PD use prosody in tasks in which prosody matters. In these studies, the findings are mixed about the presence, absence, and severity of several key features. We review those studies below.

Changes to Lexical Stress in Parkinson Disease

Darkins, Fromkin, and Benson (1988) examined the ability of people with PD to use pitch contour and pause times between syllables to distinguish noun phrases from noun compounds (e.g. black *board* and *black*board). Participants read sentences to describe a presented picture. The researchers found that people with PD did not use pitch contour to distinguish between the syllables of either noun phrases or noun compounds, nor did they produce a significant difference in the duration of the pause between the syllables of the target. However, healthy controls marked the noun phrases with a significant difference in the duration of the pauses between syllables, while they marked noun compounds with a significant difference in the pitch between syllables. Noun phrases typically have an iamb pattern (weak-strong), while noun compounds typically have a trochaic pattern (strong-weak), suggesting that there may be a difference in how people use prosodic cues to mark lexical stress. The results also suggest that this stress pattern differentiation is affected by PD.

Cheang and Pell (2007) used a similar lexical stress production task but required participants to respond with a carrier phrase instead of reading a sentence. In contrast to Darkins, Fromkin, and Benson (1988), Cheang and Pell found that people with PD were as capable of producing sufficient fundamental frequency changes as healthy controls, but that they were less able to use duration and intensity cues to differentiate between noun phrases and noun compounds. They did not assess pause differentiation.

Further, an associated listener study (Pell, Cheang, & Leonard, 2006) found that naïve listeners had a somewhat more difficult time correctly distinguishing between the paired productions of speakers in the PD group relative to the control group. That is, listeners struggled to identify the noun compounds (trochees) from the noun phrases (iambs). Listeners had a difficult time with the task overall, especially struggling to identify noun phrases in both the PD and control groups, so it is unclear how much the reduced duration and intensity cues affected identification. It is possible that the prosodic cues were not clear from either group of speakers.

The limited studies on the effects of PD on a person's lexical stress marking indicate that modulations of frequency may or may not be significantly affected, but that a person's ability to use intensity and duration may be negatively impacted. It is unclear whether vowel space is significantly affected in a lexical stress task, as this has not been formally studied in people with PD. These studies, along with relevant studies focused on the marking of contrastive tress in PD, are summarized in Table 2 below.

Task Differences in Assessing Dysprosody

One possible reason that the specific prosodic profile of PD has been difficult to characterize is that each study uses different tasks to measure dysprosody. Because of the many cognitive-linguistic functions served by prosody, some tasks may be better suited to elicit specific types of prosody than others. For instance, lexical stress can be elicited in nearly any context, but it may present differently in a reading task, a sentence repetition task, or a monologue.

Table 2: Changes to Prosody in Parkinson Disease (versus controls): Differentiation between Stressed and Unstressed Segments by Task and Stimulus

	Pitch	Intensity	Pause Time	Duration	Task and Stimulus
Darkins, Fromkin, & Benson (1988)	Significantly reduced differentiation on noun compounds (-); no significant difference on noun phases (=)	*[Not assessed]*	Significantly reduced differentiation on noun phrases (-); no significant difference on noun compounds (=)	No significant difference in whole-word length (=); *[Difference of duration between syllables unknown]*	Sentence reading in response to a picture
Cheang & Pell (2007)	No significant difference in f_0 marking between PD and controls (=)	Significantly reduced difference in amplitude (-)	*[Not assessed]*	Significantly reduced difference in duration (-)	Oral carrier phrase in response to a picture; Question elicitation with a carrier phrase in response to a picture following a narrative
Rusz, Cmejla, Ruzickova, & Ruzicka (2011)	Reduced f_0 variability (-)	Reduced dB variability (-)	No difference in % pause time (=), reduced # of pauses (-)	*[Not assessed]*	Sentence reading & passage reading with instructions to emphasize labeled words; monologue
Hertrich & Ackermann (1993)	No significant difference in pitch accent (=)	No significant difference in intensity accent (=)	*[Not assessed]*	Significantly reduced durational accent (-)	Oral sentence repetition
Ma, Schneider, Hoffman, & Storch (2015)	Reduced f0 variability in sentence reading *only* (-)	Significantly increased average (+)	*[Not assessed]*	*[Not assessed]*	Sentence reading, passage reading, & monologue
Lowit-Leuschel & Docherty (2001)	Increased avg f_0 for males (-); No significant difference for female avg f_0 (=); No significant difference in variability (=)	Decreased range on reading task, but not conversation task (-); no significant difference in variability (=)	*[Not assessed]*	Increased duration of unstressed vowels (-); *[Difference of duration between syllables unknown]*	Passage reading & conversation

Note: no studies with prosodic tasks have measured the articulatory-acoustic vowel space (marked by F1 and F2) as a relevant variable.

Further, some speech tasks have higher cognitive loads, relying on different combinations of neural coding and decoding mechanisms to produce output. The principles of the linguistic hierarchy suggest that specific communication deficits are more likely to appear in complex tasks than in simple tasks. If people with PD have dysprosody simply due to physiologic dysfunction, then task should not matter significantly in assessment: all productions will be similarly impaired due to factors such as respiratory or laryngeal changes. However, if there are cognitive-linguistic components to prosody, then task differences should be observed.

For example, Darkins, Fromkin, & Benson (1988) showed participants a picture and asked them to read a written sentence (a carrier phrase with the noun phrase and noun compound pairs) as a descriptor of the picture. However, Cheang & Pell (2007) showed participants the pictures, paraphrased the meaning for them, and asked them to identify the picture using a carrier phrase. Although both teams used similar paradigms to assess noun phrase and noun compound differentiation, the ability of participants to respond may have been affected by the presentation: reading and identification/repetition are different cognitive-linguistic tasks. This may account for some of the variation in the results.

Several research teams examining stress in prosody include a sentence reading task in their protocols. Some present written material for participants to read, label the words to be stressed, and give participants explicit instructions to emphasize these words (Rusz, Cmejla, Ruzickova, & Ruzicka, 2011). Others present sentences with only punctuation cues to differentiate between question and sentence intonation (Ma, Schneider, Hoffman, & Storch, 2015). Hertrich & Ackerman (1993) presented their stimulus sentences orally rather than in writing and asked participants to verbally repeat the sentence to elicit a specific contrast. In contrast, Cheang & Pell's (2007) presented a brief narrative both orally and visually before asking a question to elicit a specific contrast within a carrier phrase. Just as written versus oral presentation of stimulus material may affect the elicited speech's prosodic content, the differences in these studies' results (Table 2) suggest that the instructions given (e.g. repetition or question elicitation) could also affect prosodic output.

Ma, Schneider, Hoffman, and Storch (2015) assessed differences in speakers' prosody across tasks, eliciting speech in sentence reading, passage reading, and monologue contexts. Acoustic analysis revealed minimal differences between the way that people with PD and healthy controls marked stress using pitch, intensity, and overall speech rate, with reduced pitch variability specifically on the sentence reading task. People with mild PD were also noted to be louder than both controls and people with moderate-severe PD. Importantly, they found significant differences across tasks in the use of pitch, intensity, and speech rate.

This is in contrast with an earlier study by Lowit-Leuschel & Docherty (2001) that found no significant differences between how people with PD used prosodic cues in conversational and reading tasks. Lowit-Leuschel and Docherty claim that this shows that people with PD do not respond differently to elicitation tasks. However, while both studies included reading tasks with varied intonational contrasts, the nature of the spontaneous speech tasks were different: Ma, Schneider, Hoffman, & Storch (2015) recorded speakers producing a spontaneous monologue, while Lowit-Leuschel & Docherty recorded a conversation between the participant and the researcher. Further, the participants with PD in the Lowit-Leuschel & Docherty study were analyzed together as a single dysarthric group along with other participants with multiple sclerosis and motor neuron disease, limiting the generalizability of these results to PD. Lowit-Leuschel & Docherty also found minimal group differences within task: males with dysarthria had a higher average f_0 than controls (with no group difference for females), speakers with dysarthria had a decreased intensity range compared to controls, and the duration of the unstressed vowels of speakers with dysarthria was longer than the duration of unstressed vowels spoken by controls (though there was no comparison across syllables).

These results suggest the first of two problems that need to be solved in research about the stress-marking behavior of people with PD. The variations in prosodic marking behaviors suggest that people with PD mark stress differently depending on the speech elicitation task, as do all speakers of Standard American English. However, it is not clear whether people with PD respond more differently to elicitation tasks. Examining multiple tasks of differing levels of complexity should allow for the characterization of different stress marking behaviors. The second problem relates to the cognitive changes observed in people with PD.

Associated Cognitive Changes in Parkinson Disease

One of the reasons that cognitive load is especially significant for people with PD is that habitual control is diminished compared to healthy adults, likely due to basal ganglia dysfunction (Zesiewicz, Baker, Wahba, & Hauser, 2003; Ziemssen & Reichmann, 2010; Redgrave et al., 2010; Jahanshahi, Obeso, Rothwell, & Obeso, 2015). Sapir (2014) suggests that many aspects of prosody are habitual rather than goal-directed, so that while a person with PD is capable of producing meaningful contrasts given a sufficient external cue, their internal cueing is diminished (Sadagopan & Huber, 2007; Lansford, Liss, Caviness, & Utianksi, 2011; Alvar, Lee, & Huber, 2019), and overall vocal attention, effort, and vigilance are reduced compared to healthy controls.

Given external cues, people with PD can produce speech that approaches typical speech (Ramig, Sapir, Fox, & Countryman, 2001; Sadagopan & Huber, 2007; Darling & Huber, 2011).

For instance, Whitfield and Goberman (2014) found that, when prompted to read the Rainbow Passage "clearly" instead of habitually, the vowel space of people with PD increased, approaching the vowel space of age- and sex-matched healthy controls. Lam & Tjaden (2016) found similar results in sentence reading tasks with varied speaking condition instructions (e.g. clear, over-enunciate, & hearing impaired), during which people with PD increased vowel space, duration, fundamental frequency, and intensity. Neither study focused on prosodic adequacy, but the enhancement of these features led listeners to rate the speech of the participants as more intelligible in clear than in habitual speech conditions, suggesting that when directed to, people with PD can adjust their habitual speech production. These findings support the hypothesis that more direct elicitation of prosody may lead to more typical productions from people with PD. In prosodic studies, external cues (e.g. bolded words, being told to speak in a particular way, etc.) will lead people to produce more emphatic contrasts than internal cues. This is useful, but external cues are not always available. Naturalistic tasks rely more on internal cues. The most effective speech tasks for either a research study or a clinical treatment are those that more closely resemble everyday communication.

Naturalistic Assessment of Prosody in Parkinson Disease

The aim of this study is to describe how people with PD modulate prosodic variables (i.e., f_0, intensity, duration, and acoustic-articulatory vowel space as measured by the first and second formants) during a natural, prosody-specific task. We will compare the naturalistic task (map description) to two more commonly used tasks: word production in isolation and word production in lists. All tasks used pictures to support production. None of the tasks used reading for elicitation. We will demonstrate the effects of task on the marking of lexical stress, compared to age- and sex-matched controls. The long-term goal of this research program is to understand the changes to prosody in PD and the effects of task on these assessments.

Hypotheses

The prosody of participants with PD will be reduced relative to age- and sex-matched peers, trending towards monopitch, monoloudness, monoduration, and neutralized vowels, with greater declines on tasks with greater cognitive load demands:

- Subjects with PD and controls will produce equivalent prosodic contrasts in an isolated picture naming lexical stress task.
- Compared to their own productions in isolation and list intonation, both participants with PD and controls will produce less emphatic lexical contrasts on a naturalistic map description task. Further, people with PD will demonstrate a sharper decline in the marking of lexical stress across target words on the map task than controls.
- The variable that will be the most different between people with PD and controls will be duration, with the reduction of durational contrasts between the syllables of both trochees and iambs in people with PD.

METHODS

Participants

Fourteen individuals with a diagnosis of idiopathic PD and thirteen age- and sex-matched controls participated in this study. One participant with PD and one control did not complete the portion of the test protocol analyzed for this study. An additional participant with PD was excluded from the analysis due a lack of an age- and sex-matched control. Therefore, twelve individuals with PD were included in the final analyzed sample: six females and six males between the ages of 68.8 and 85.2 years (mean age 76.3 ± SD 5.13 years). The twelve participants were closely age- and sex-matched to healthy controls between the ages of 66.7 and 85.5 years (mean age 77.1±5.40 years). A *t test* on the ages of the participants showed no significant differences in age between groups (t = -0.3587, p = 0.723).

All participants spoke a North Midland dialect of American English, had no formal vocal training, had not smoked for at least five years, had no current respiratory infections, had no history of significant respiratory illness other than allergies or asthma, and had no history of head and neck cancer or surgery. All participants with a history of allergies or asthma were stable and had their conditions controlled by medicine. All participants passed a hearing screening at 40 dB at 0.5, 1, and 2 kHz except F07PD, M04PD, and M07OC. With amplification, these participants' hearing was considered acceptable for the testing protocol. All participants also had no history of neurological disease except for PD. Most participants with PD were taking anti-Parkinsonian medications, and their speech measurements were taken within 1-3 hours of taking their medications. Additionally, M04PD had a deep brain stimulation implant. Several participants had enrolled in speech therapy prior to the study. None were currently enrolled. Participants were given the Cognitive Linguistic Quick Test (CLQT) prior to data collection, though they were not required to receive scores within normal limits to continue the study. History of speech therapy and CLQT scores are included in Table 3.

Two speech-language pathologists (not involved in the study) with experience diagnosing and treating adults with motor speech disorders rated the speech severity of all participants. They listened to a 30-second monologue sample taken from the approximate middle of a 2-minute monologue. These samples were intensity-normalized and presented once over headphones, blocked by speaker sex with presentation randomized within sex and raters blinded to diagnosis.

Each rater ranked the sample on a visual analog scale with anchors from normal to very severe. Their rating mark was measured in millimeters and then converted to a percentage score, with a higher number indicating greater severity. The average of the two ratings was taken as the final severity score. However, if there was a greater than 20% difference between the ratings, a 3rd SLP (Huber) also rated the sample. The average of this third rating and the closest of the original two ratings was used as the final severity score. Three individuals were rated a third time. Speech severity ratings and demographic information are presented in Table 3.

Equipment

Speech samples were transduced using a condenser microphone with a flat-frequency response from 50 Hz-20kHz. The microphone was held at a constant distance six inches from the speaker's mouth, placed at a 45-degree angle. A sound-level meter coupled to the microphone was used to calibrate the microphone, and the gain was factored into the calibration of the acoustic signal. The acoustic signal from the microphone was recorded to a digital audio tape, and then digitized for computer analysis using the software program Praat. The audio signal was recorded at 44.1 kHz, resampled at 18 kHz, and then low-pass filtered at 9kHz.

Table 3: Participant Demographic Information

Pair	Participant	Age (y;m;d)	Years Since Diagnosis	CLQT	Speech Severity (%)	Hx Speech Tx
1	F02PDL	72;2;11	11	WNL (4.0)	43	Low volume
	F13OCL	76;9;0	n/a	WNL (4.0)	2.5	n/a
2	F04PDL	76;11;17	7	WNL (4.0)	11.4	No
	F05OCL	77;1;11	n/a	WNL (4.0)	7.1	n/a
3	F05PDL	82;10;18	15	Mild (2.8)	*	No
	F17OCL	83;3;4	n/a	WNL (4.0)	*	n/a
4	F06PDL	75;4;3	5	WNL (4.0)	*	No
	F02OCL	78;6;20	n/a	WNL (4.0)	4.7	n/a
5	F07PDL	75;11;18	1	WNL (4.0)	10	No
	F08OCL	77;2;24	n/a	WNL (3.6)	*	n/a
6	F08PDL	68;9;17	3	WNL (4.0)	*	No
	F07OCL	69;7;20	n/a	WNL (4.0)	1	n/a
7	M04PDL	73;5;25	9	WNL (4.0)	82	Low volume, pitch breaks
	M07OCL	74;0;23	n/a	WNL (4.0)	7.5	n/a
8	M09PDL	76;8;7	13	Moderate (1.8)	73	Speech clarity
	M11OCL	77;3;0	n/a	WNL (4.0)	3	n/a
9	M10PDL	73;7;14	9	Mild (3.4)	8.9	Word finding
	M06OCL	74;1;20	n/a	WNL (4.0)	2	n/a
10	M11PDL	85;2;10	7	WNL (3.8)	35.5	No
	M09OCL	85;6;13	n/a	WNL (4.0)	0.3	n/a
11	M12PDL	69;10;9	4	WNL (3.8)	*	No
	M13OCL	66;8;5	n/a	WNL (4.0)	*	n/a
12	M13PDL	84;2;0	2	WNL (3.6)	*	No
	M10OCL	84;7;9	n/a	WNL (4.0)	*	n/a

Abbreviations: n/a, not applicable; * data unavailable; WNL within normal limits; CLQT Cognitive Linguistic Quick Test
**Data are organized in pairs of participants with PD (participant numbers ending in PDL) and age- and sex-matched typical older adults (participant numbers ending in OCL). Higher numbers for speech severity indicate more severe speech ratings.

Stimulus

Three tasks were developed to elicit lexical stress on target words for this study. The first task was a picture identification task, in which a picture was displayed on a computer monitor and the participant was asked to name it, eliciting lexical stress for trochaic and iambic stress patterns in isolation. The second task was a picture identification task (Appendix A), in which four pictures were displayed together and the participant named all four pictures in list format. This was used to elicit trochaic and iambic word stress in pseudo-connected speech with list intonation. The targets of interest were always in the second or third position. Participants were instructed to string the words together as if in a sentence, without pauses between words, to mimic connected speech and force coarticulation. Participants were prompted to try again if pauses became subjectively too long. Most participants were able to complete this task with minimal verbal cues, but some data includes trials that contained longer pauses between words for those who found the task taxing.

The third task was a map description task, in which the participant was asked to describe a map of a town (Appendix B) and a map of a zoo (Appendix C). Each map was displayed on a computer monitor. For both maps, the participant was first asked to describe what they saw. For the town map, the participant was asked to give directions between two distinct points on the map. Both maps elicited lexical stress in connected speech.

During data collection, participants completed additional speech tasks including monologue, passage reading, and the production of declarative and interrogative intonation, but data will not be presented from these tasks here. The order of presentation of all speech tasks was randomized during each session.

The participants included in the study completed all required tasks except for one. M09PD requested a break during the completion of the second picture identification task (picture listing). Data could only be gathered for one of four target words in this task. No other participants have missing data.

Acoustic Measurements and Derived Values

For all three lexical stress tasks (isolated picture identification, list picture identification, and map description), the token words of interest were extracted from the corresponding sound file and clipped to include only the word of interest. Five acoustic measures were taken for each syllable: mean pitch, mean intensity, vocalic segment duration, and formants 1 and 2 (F1 and F2) at 20%, 50%, and 80% of the duration of the vocalic segment. The analysis was completed using Praat software (Boersma & Weenink, 2019). After isolating and highlighting the vocalic segment of each syllable, the mean pitch and intensity values for each vocalic segment were taken from Praat's automatic calculation for "get pitch" and "get intensity" respectively. Duration was taken from Praat's automatic display of duration of the selected vocalic segment.

The F1 and F2 were taken from the "get *n* formant" feature in Praat at the measured 20%, 50%, and 80% total duration times of the vocalic segment. The F1 and F2 frequency (*f*) measures were then converted to Bark scale measures using the formula:

$$13*\arctan(0.00076f) + 3.5*\arctan((f/7500)^2) \quad [1]$$

While the Bark-scale converted formants were analyzed on their own as response variables, they were also used to calculate the Euclidean Distance. The Euclidean Distance is a composite measure of F1 and F2 that shows the distance of any vowel from the relative acoustic center of gravity. Low Euclidean Distance values are closer to the acoustic center of gravity, while high values are far from it. It follows that unstressed, neutral vowels ought to have lower Euclidean Distances, while stressed vowels ought to have higher Euclidean Distances. As formant values were taken near the beginning (20%), middle (50%), and end (80%) of each vocalic segment, the Euclidean Distance was calculated twice for each vowel, to represent the first and second halves of each vowel. The formulas used were:

$$\sqrt{(F1_{50\%} - F1_{20\%})^2 + (F2_{50\%} - F2_{20\%})^2} \quad \text{and} \quad \sqrt{(F1_{80\%} - F1_{50\%})^2 + (F2_{80\%} - F2_{50\%})^2} \qquad [2]$$

Finally, the Pairwise Variability Index (PVI) (Grabe & Low, 2002) is a technique used to quantify the differences in lexical stress as marked by different prosodic factors (i.e. duration, mean pitch, and mean intensity). Using duration (D) as an example, the formulas used were:

$$|D_{Syllable1} - D_{Syllable2}| \,/\, |(D_{Syllable1} + D_{Syllable2})/2| \qquad [3]$$

This results in values ranging from 0 (no difference in the variable) to $1.\overline{99}$ (very high difference in the variable). This provides an alternative, equalized index of overall differences between syllables.

Correcting Pitch-Tracking Errors for f_0 Measures

While Praat's "get pitch" function is usually adequate to measure the f_0 of words produced with typical modal voice, words produced with breathy voice, pressed voice, vocal fry, or other vocal timbres tend to distort Praat's pitch calculations. The following types of pitch-tracking errors may occur when the "get pitch" function is selected in Praat:

1. Tracking a subharmonic frequency (2x lower than the perceptual pitch) (Figure 1)
2. Not tracking any fundamental frequency
3. Tracking an overtone frequency (2x higher than the perceptual pitch)
4. Tracking a fundamental frequency in which no voicing occurs (usually during fricatives)
    a. Note: This should not be a problem, as only vocalic segments are being analyzed.

Changes in vocal quality are prevalent in all older adults, but are especially common in people with PD. Rather than discarding this data, strategies were implemented to correct for these pitch-tracking errors, as follows:

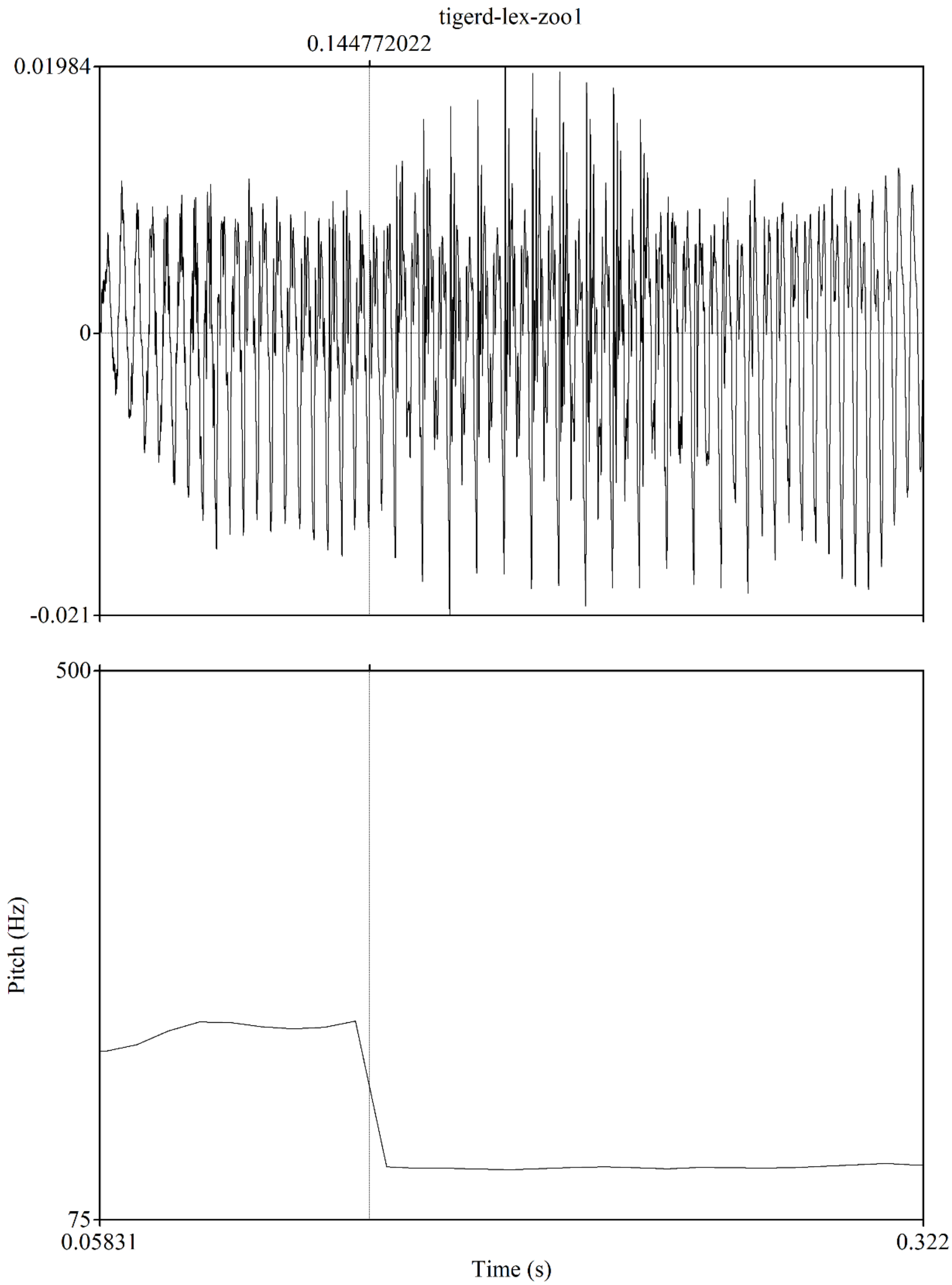

Figure 1: Praat Tracking a Subharmonic Frequency

This is an example of Praat tracking a subharmonic frequency during a spontaneous production of the word “tiger” (first vocalic segment shown only)

1. Error: Praat is tracking a subharmonic frequency (2x lower than the perceptual pitch)
    a. Record the total duration of the vocalic segment (d_t)
    b. If there is any portion of the vocalic segment with normal pitch tracking, measure this f0 with Praat's "get pitch" function ($f0_1$). Record the duration of this normal segment (d_1).
        i. If Praat's pitch tracking includes a sharp downward slope during which it begins to track the subharmonic instead of the fundamental frequency (as in Figure 1), include the first half of the downward slope in the pitch and duration measures (see the dividing line at 0.144772 s in Figure 1).
        ii. The normal segment (d_1) in Figure 1 is measured from 0.05831s to 0.144772s.
    c. Measure from the end of the previous segment (d_1) to either the end of the vocalic segment (if Praat continues to track the subharmonic) or halfway through a corresponding sharp upward slope (if Praat begins to track the correct fundamental frequency again).
        i. In the example case of Figure 1, the vocalic segment ends with Praat still tracking the subharmonic. The subharmonic segment (d_2) in Figure 1 is measured from 0.144772s to 0.322s.
        ii. Measure any tracked subharmonic frequency with Praat's "get pitch" function ($f0_2$) and multiply the subharmonic frequency by 2. Record the duration of this subharmonic segment (d_2).
    d. Repeat until the entire vocalic segment has been measured. The formula for the corrected f0 is:

$$(f0_1*(d_1/d_t)) + ((f0_2*2)*(d_2/d_t)) + \ldots + (f0_n*(d_n/d_t)) \qquad [4]$$

where only subharmonic segments include a multiplication of f0 by 2.

2. Error: Praat is not tracking any fundamental frequency while voicing is occurring
    a. Record the total duration of the vocalic segment (d_t)
    b. Visually identify an approximate glottal wave pattern (similar repeating structure).
    c. Measure 3-4 cycles (c_1) and record the duration of this segment (d_1). Divide the cycles by the duration to derive the frequency (cycles per second), giving you $f0_1$.
        i. Note: it may be appropriate to multiple the derived frequency by 2 for similar reasons as strategy #1.
    d. Repeat until the entire vocalic segment has been measured.
    e. The formula for the corrected f0 is:

$$(f0_1*(d_1/d_t)) + ((f0_2)*(d_2/d_t)) + \ldots + (f0_n*(d_n/d_t)) \quad [5]$$

3. Error: Praat is tracking an overtone frequency (2x higher than the perceptual pitch).
    a. This strategy is identical to #1 but involves dividing the tracked frequency by 2 instead of multiplying it.

Correcting Formant-Tracking Errors for F1 and F2 Measures

While Praat's "get *n* formant" feature is usually adequate to measure the formants of words produced with typical modal voice, words produced with breathy voice, pressed voice, vocal fry, or other vocal timbres tend to distort the formants. These errors were marked visually as the sudden disappearance or shift of a formant amidst regular tracking. It was not assumed that just because a value was outside of the typical expected range of a vowel that the formant was incorrect, although outliers were reexamined. Rather than discarding this data, strategies were implemented to correct these formant-tracking errors, as follows:

1. Spectral Slice
   a. Select Spectrum > View Spectral Slice
   b. Visually identify the appropriate peaks. The nearest peak in Praat can be quickly identified with Ctrl+K.
2. Identify nearest effectively tracked formant or formants
   a. “Get *n* formant” for effectively tracked formant before and/or after target.
   b. If only one adjacent tracked formant is available, use this as the formant of the target.
   c. Otherwise, take the average of the formants before and after the target (as many as necessary).

If neither of these methods were successful to produce an accurate formant value, Praat’s formant-tracking feature was turned off and an approximate value was determined by careful visual selection of what appeared to be the formant bands. Of the nearly 3,500 formant values measured, this was done fewer than ten times, and only after the other two options had been attempted.

Table 4: Stimulus Words to be Analyzed by Task

Token of Interest	Picture Identification Task, Isolated	Picture Identification Task, List Intonation	Picture Description Task, Maps
Balloons (iamb)	√	√	√
Coffee (trochee)	√	√	√
Giraffe (iamb)	√	√	√
Tiger (trochee)	√	√	√

RESULTS

Mixed model analysis of variance (ANOVA) with repeated measures was used to determine whether there were significant effects of Group (Parkinson disease, Age- and Sex-Matched Controls), Task (Isolated, List, Spontaneous Speech), Syllable Number (first, second), or Stress Pattern (trochaic (strong-weak), iambic (weak-strong)) on the dependent variables. Interaction effects were also examined among the factors.

There was one significant 3-way interaction effect (Task x Syllable Number x Stress Pattern) found for duration of the vowel (discussed below). There were no other significant 3-way interaction effects (Group x Task x Syllable Number, Group x Task x Stress Pattern, Group x Syllable Number x Stress Pattern) and no significant 4-way interaction effects (Group x Task x Syllable Number x Stress Pattern) on the dependent variables. Summaries of the statistical results, along with mean values, are provided in Tables 5 through 16, organized by factor. For significant main effects of task and all significant interaction effects, the Tukey HSD alpha value is provided in the text. The alpha level was set at $p < .05$.

Duration of Vowel

For <u>duration of vowel</u>, there were significant main effects of <u>syllable number</u> (Table 7) and <u>stress pattern</u> (Table 8). There were also significant interaction effects for <u>task x syllable number</u> (Table 12), <u>task x stress pattern</u> (Table 13), <u>syllable number x stress pattern</u> (Table 14), and <u>task x syllable number x stress pattern</u> (Table 15). There were no other significant main or interaction effects.

Although there was a three-way interaction, the patterns across syllable number and stress pattern were the same for all tasks. For <u>all words in all tasks</u>, regardless of who the words were produced by (task x syllable number x stress pattern), the strong (first) syllable in trochees was longer than the weak (first) syllable in iambs ($p < .001$); the weak (first) syllable in iambs was shorter than the strong (second) syllable in iambs ($p < .001$); and the weak (second) syllable in trochees was shorter than the strong (second) syllable in iambs ($p < .001$). However, the strong (first) syllable in trochees was not significantly longer than the weak (second) syllable in trochees across words produced in isolation, ($p = .864$), in list intonation ($p = .923$), or in spontaneous speech ($p = 1.000$). There were two significant differences across tasks. The strong (second) syllable in iambs was longer when produced in isolation than in either the list ($p < .001$) or map tasks (p = .013).

Mean Pitch of Vowel

For mean pitch of vowel, there was a significant main effect of group (Table 5). There were no other significant main effects and no significant interaction effects. Across all syllables in all words in all tasks, the mean pitch of vowels produced by people with PD was higher than the mean pitch of vowels produced by controls ($p < .001$).

Mean Intensity of Vowel

For mean intensity of vowel, there were significant main effects of syllable number (Table 7) and stress pattern (Table 8). There were also significant interaction effects for syllable number x stress pattern (Table 14). There were no other significant main or interaction effects.

For all words in all tasks, regardless of who the words were produced by (syllable number x stress pattern), the mean intensity was higher in the strong (first) syllable of trochees than the weak (second) syllable of trochees ($p < .001$), and was lower in the weak (second) syllable of trochees than the strong (second) syllable of iambs ($p < .001$). However, there were no significant differences in the mean intensity between the strong (first) syllable of trochees and the weak (first) syllable of iambs (p = .733) or the strong (second) and weak (first) syllables of iambs (p = .633).

Pairwise Variability Index of Duration

For the pairwise variability index of duration, there was a significant main effect of stress pattern (Table 8) and a significant interaction effect for task x stress pattern (Table 13). There were no other significant main or interaction effects.

For all words produced, regardless of who the words were produced by, the tendencies across stress pattern were nearly the same for all tasks (task x stress pattern). There was greater differentiation in duration between the syllables of iambs than trochees (p < .001). There was one significant difference across tasks. There was greater differentiation in duration between the syllables of iambs produced in isolation than iambs produced in list intonation (p < .001).

Pairwise Variability Index of Mean Pitch

For the pairwise variability index of pitch, there were significant main effects of group (Table 5), task (Table 6), and stress pattern (Table 8). There were also significant interaction effects for group x stress pattern (Table 11) and task x stress pattern (Table 13). There were no other significant main or interaction effects.

For all words produced, regardless of task (group x stress pattern), there was greater pitch differentiation between the syllables of trochees than iambs for both people with PD (p = .013) and older adults (p < .001). Across groups, there was greater pitch differentiation between the syllables of trochees produced by older adults than the syllables of trochees produced by adults with PD ($p < .001$). But there was no significant difference across groups in the pitch differentiation between the syllables of iambs ($p = .589$).

Relative to the task x stress pattern interaction effect, there was greater pitch differentiation between the syllables of trochees than iambs ($p < .001$) in isolation. Similarly, in spontaneous speech, there was greater pitch differentiation between the syllables of trochees than iambs ($p = .007$). However, there was no significant difference in the pitch differentiation between the syllables of trochees and iambs produced with list intonation ($p = .892$). There were also two significant differences across task relative to stress pattern. There was greater pitch differentiation between the syllables of trochees produced in isolation and spontaneous speech than the syllables of trochees produced in list intonation ($p < .001$ for both).

Pairwise Variability Index of Mean Intensity

For the pairwise variability index of intensity, there were significant main effects of task (Table 6) and stress pattern (Table 8). There were no other significant main effects and no significant interaction effects. For task, there was overall greater differentiation in intensity in words produced in isolation than in words produced in list intonation ($p = .022$), though there were no significant differences in the differentiation of intensity between words produced in isolation vs spontaneous speech ($p = .552$) or between list intonation vs spontaneous speech ($p = .230$). For the main effect of stress pattern, there was greater differentiation in intensity in trochees than iambs ($p < .001$).

Bark Scale F1 (20%, 50%, and 80%)

For the Bark Scale measure of F1 at the three measured points of the vowel (20%, 50%, and 80%), there were significant main effects of group (Table 4), syllable number (Table 7), and stress pattern (Table 8). There were significant interaction effects for syllable number x stress pattern (Table 14) at all three measured points. For the Bark Scale measure of F1 at two of the three measured points of the vowel (50% and 80%), there was also a significant main effect of task (Table 6). There were no other significant main or interaction effects.

For the main effect of group, across all syllables in all words in all tasks, the Bark scale measure of F1 was higher in vowels produced by controls than in the vowels produced by people with Parkinson disease (p = .018, .004, .004 for 20%, 50%, and 80% respectively).

For the main effect of task, the Bark scale measure of F1 was higher in words produced in spontaneous speech than in words produced in isolation at the 50% (p = .014) and 80% (p =.017) measured points, but not at 20% (p = .5657). There were no significant differences in the Bark scale measure of F1 between words produced in isolation vs list intonation (p = .997, .737, .709) or between list intonation vs spontaneous speech (p = .566, .102, .129) at any of the three points.

For the interaction of stress pattern x syllable number, the Bark scale measure of F1 was higher in the strong (first) syllable of trochees than the weak (first) syllable of iambs ($p < .001$), was higher in the strong (first) syllable of trochees than the weak (second) syllable of trochees ($p < .001$), was lower in the weak (first) syllable of iambs than the strong (second) syllable of iambs ($p < .001$), and was lower in the weak (second) syllable of trochees than the strong (second) syllable of iambs ($p < .001$).

Bark Scale F2 20%

For the Bark Scale measure of F2 at 20% of the duration of the vowel, there were significant main effects of task (Table 6) and syllable number (Table 7). There were also significant interaction effects for syllable number x stress pattern (Table 14). There were no other significant main or interaction effects.

For task, the Bark scale measure of F2 at 20% of the vowel was higher in words produced in list intonation than in words produced in isolation ($p < .001$), but there was no significant difference between words produced in isolation vs spontaneous speech ($p = .069$) or between list intonation vs spontaneous speech ($p = .257$).

For all words in all tasks, regardless of who the words were produced by (syllable number x stress pattern), the Bark scale measure of F2 at 20% was lower in the strong (first) syllable of trochees than the weak (first) syllable of iambs ($p < .001$), was lower in the strong (first) syllable of trochees than the weak (second) syllable of trochees ($p < .001$), and was higher in the weak (second) syllable of trochees than the strong (second) syllable of iambs ($p < .001$). However, there was no significant difference in the Bark scale measures of F2 at 20% between the weak (first) and strong (second) syllable of iambs ($p = .994$).

Bark Scale F2 50%

For the Bark Scale measure of F2 at 50% of the duration of the vowel, there were significant main effects of syllable number (Table 7) and stress pattern (Table 8).
There were also significant interaction effects for task x stress pattern (Table 13) and syllable number x stress pattern (Table 14). There were no other significant main or interaction effects.

Relative to the task x stress pattern interaction effect, the Bark scale measure of F2 at 50% was higher in trochees than in iambs ($p < .001$) for words produced in isolation, regardless of who the words were produced by. However, there was no significant difference in the Bark scale measure of F2 at 50% between trochees and iambs produced with list intonation ($p = .961$)

or in spontaneous speech ($p = 1.000$). The Bark scale measure of F2 at 50% was lower in iambs produced in isolation than in those produced in list intonation ($p = .0422$) or spontaneous speech ($p = .0441$).

For all words in all tasks, regardless of who the words were produced by (syllable number x stress pattern), the Bark scale measure of F2 at 50% was lower in the strong (first) syllable of trochees than the weak (second) syllable of trochees ($p < .001$), was lower in the weak (first) syllable of iambs than the strong (second) syllable of iambs ($p < .001$), and was higher in the weak (second) syllable of trochees than the strong (second) syllable of iambs ($p < .001$). However, there was no significant difference in the Bark scale measure of F2 at 50% between the strong (first) syllable of trochees and the weak (first) syllable of iambs ($p = .970$).

Bark Scale F2 80%

For the Bark Scale measure of F2 at 80% of the duration of the vowel, there were significant main effects of syllable number (Table 7) and stress pattern (Table 8). There was also a significant interaction effect for task x stress pattern (Table 13). There were no other significant main or interaction effects.

For the main effect of syllable number (all words in all tasks, regardless of who the words produced by or the stress pattern of the word), the Bark scale measure of F2 at 80% was higher in the second syllable than the first syllable ($p < .001$). For the task by stress pattern effect, the Bark scale measure of F2 at 80% was higher in trochees than in iambs in all tasks (isolation: $p < .001$; list intonation: $p = .003$; spontaneous speech: $p = .004$).

Euclidean Distance of F1 and F2 (first half of vowel)

For the Euclidean Distance for combined F1 and F2 during the first half of the vowel, there were significant main effects for syllable number (Table 7) and stress pattern (Table 8). There were also significant interaction effects for task x stress pattern (Table 13) and syllable number x stress pattern (Table 14). There were no other significant main or interaction effects.

For all words in all tasks, regardless of who the words were produced by (syllable number x stress pattern), the Euclidean distance was smaller in the weak (first) syllable of iambs than the strong (second) syllable of iambs ($p < .001$), and smaller in the weak (second) syllable of trochees than the strong (second) syllable of iambs ($p < .001$). However, there were no significant difference in the Euclidean distance between the strong (first) syllable of trochees and the strong (second) syllable of iambs ($p = .963$) or between the strong (first) and weak (second) syllables of trochees ($p = .354$).

For the task x stress pattern interaction effect, a difference was only seen in the words produced in the list task. In list intonation, the Euclidean distance for the first half of the vowels was smaller in trochees than in iambs ($p < .001$). However, there were no significant differences in the Euclidean distance between trochees or iambs produced in either isolation ($p = .995$) or in spontaneous speech ($p = .200$).

Euclidean Distance of F1 and F2 (second half of vowel)

For the Euclidean Distance for combined F1 and F2 for the second half of the vowels, there were significant main effects for syllable number (Table 7) and stress pattern (Table 8). There were also significant interaction effects for syllable number x stress pattern (Table 14). There were no other significant main or interaction effects.

For all words in all tasks, regardless of who the words were produced by (syllable number x stress pattern), the Euclidean distance for the second half of the vowels was greater in the strong (first) syllable of trochees than the weak (first) syllables of iambs ($p < .001$), greater in the strong (first) syllable of trochees than the weak (second) syllable of trochees ($p < .001$), and greater in the weak (first) syllable of iambs than the strong (second) syllable of iambs ($p = .003$). However, there were no significant difference in the Euclidean distance between the weak (second) syllable of trochees and the strong (second) syllable of iambs ($p = .064$).

DISCUSSION

The Effects of Parkinson Disease on the Marking of Lexical Stress

This study was completed to explore the question of whether PD affects the ability of a person to adequately differentiate between the syllables of two-syllable trochaic and iambic words. The results of this study show that there are very few differences in the way that people with PD mark lexical stress compared to their age- and sex-matched peers. However, differences across tasks (isolation, list, and spontaneous speech) were prominent.

Turning first to the group differences, there were three significant differences noted between people with PD and their age- and sex-matched peers. Two were true across all tasks and all words, representing global differences rather than specific differences in the marking of lexical stress. First, people with PD had a higher mean pitch than controls. This likely represents changes to laryngeal physiology due to vocal fold bowing. Second, people with PD had a lower F1 across all vowels than controls, suggesting that they are not opening their mouths as wide or moving their tongues as much for any given speech task. This provides further evidence for the tendency toward generalized neutralization of vowels, leading to potentially reduced stress differentiation.

The final major difference is significant to the marking of lexical stress. Both people with PD and their age- and sex-matched controls differentiated stress patterns using pitch (PVI f0) more to show a difference between the syllables of trochees than iambs. However, people with PD did not have as much pitch distinctiveness between trochee syllables as controls. But the pitch distinctiveness in iambs was similar for people with PD and controls. Further, people with PD used distinction in the duration and intensity domains similarly to controls. These findings are consistent with the majority of researchers who have found that people with PD are able to mark lexical stress with pitch, but that pitch distinctions are reduced. The current study adds to this literature, clarifying that the primary difference in pitch distinctions are in trochees rather than iambs.

Most other variables were consistent between people with PD and their age- and sex-matched controls. The crucial ability to differentiate iambs from the dominant trochaic metrical structure of Standard American English is preserved. Lexical stress appears to not be significantly affected by having PD, and therefore is not, in and of itself, a clear component of the hypokinetic dysarthria.

The Effects of Task on the Marking of Lexical Stress

Many research and clinical practice tasks focus on recording words spoken in isolation or in list format. The results of this study demonstrate that words in isolation tend to be over-articulated, with stress patterns and syllabic distinctions overemphasized compared to spontaneous speech. The results around list intonation are less clear, sometimes differing from words in isolation or spontaneous speech, but less systematically. Of note, most of the results in this data suggest that the marking of lexical stress of words in isolated speech had more in common with words produced in spontaneous speech than with list intonation. This suggests that words in isolation are fine for learning a task, but that we must transition to connected speech quickly to increase carry-over and to ensure that stress patterns are naturalistic after therapy. Words in list intonation are not likely to be effective for studying or treating dysprosody unless something specific is sought about the use of list intonation.

Differences in Marking of Lexical Stress for Trochees and Iambs

In addition to designing tasks to elicit target words in connected, spontaneous speech, it is also important to separate words by stress pattern. This study demonstrated differences in the marking of lexical stress between trochees and iambs. Assuming that trochaic stress is marked the same as iambic stress could lead to incorrect conclusions about how effectively a patient is marking stress.

Although the focus of this study was determining the effects of prosodic tasks on the marking of lexical stress in people with PD, it also confirmed that adult speakers without PD mark trochees differently than they mark iambs, and that this pattern is not significantly altered by PD. Both groups tended to use duration the most to mark stress differences in syllables, particularly in iambs. Trochees were distinguished by pitch and intensity more than iambs. Differences in several of the measures in the current study were larger across the syllables in iambs than in trochees (Duration of the vowel, PVI Duration, Euclidean distance for first half of the vowel).

These finding are consistent with those reported by Goffman and Malin (1999). While adults produce amplitude and temporal modulations between both trochees and iambs, the modulations between the syllables of iambs tend to be much greater than those of trochees. Goffman and Malin hypothesized that iambs are more strongly marked because they break the typical prosodic pattern of standard American English (strong-weak), and thus, speakers draw attention to this difference. However, some of the dependent measures were used more prominently to distinguish syllables in trochees than iambs (PVI intensity, PVI pitch, F2 at 20% and 80% of vowel). These findings underscore the difference in cues used to convey stress patterns in trochees and iambs.

The Significance of Formants in Lexical Stress

While acoustic formants have been examined in the production of lexical stress in other populations, it has not formally been assessed in people with PD until this study. It was ultimately the formant data (and the Euclidian Distance data derived from it) that proved to be the most interesting. Vowel quadrilaterals are provided in Appendix D, divided by task and gender but combining groups together. The F1 data revealed an expected dichotomy: people with Parkinson disease have smaller overall jaw and tongue excursions in the production of stressed syllables (Forrest, Weismer, & Turner, 1989; Robertson & Hammerstad, 1996; Darling & Huber, 2011; Walsh & Smith, 2012; Kearney et al., 2017). This is consistent with other findings about people with PD, which describe them has having overall reduced limb range and speed of movement (Morris, 2000; Jankovic, 2008; Mazzoni, Shabbott, & Cortés, 2012). However, in spontaneous speech, F1 was higher for both groups than in isolated word production, suggesting that the differences in articulation may be exaggerated in isolated word production as compared to spontaneous speech.

In F1, the differences across syllables reflect stress patterns rather than syllable number. The stressed vocalic segment in the iambs “balloon” (low F1 value in /u/) and “giraffe” (high F1 value in /ae/) are compared to the stressed vocalic segments in the trochees “coffee” (mid-high F1 value in /ɔ/) and the diphthong /a͡ɪ/ in “tiger” (starting with a high F1 and closing with a low F1). While it is expected that this mix of mostly high F1 values would have a higher F1 than the comparative mid-to-low F1 values in the unstressed syllables (/ə/, /i/, and /ɚ/) respectively, the phonetic content doesn’t explain all the differences. Regardless of the mix of phonetic content, the stressed syllables consistently have a higher F1 value than the unstressed syllables (within and across word comparisons). The Euclidean distance findings also follow stress patterns, rather than syllable number, suggesting there is more change in formants across stressed syllables.

There are no differences across the two groups for F2. As F2 correlates most strongly with how forward vs. backward the tongue is in the mouth, this suggests that either 1) this component of prosodic articulation is not significantly affected by PD, 2) the phonemic content of the token words obscured any possible differences, or 3) a broader samples of vowels needs to be considered to fully appreciate any differences in F2 production in PD.

Instead of group differences, however, the strongest observed effect for F2 is a positional one. Across all words at the 50% and 80% time points, the second syllable had a higher F2 (more fronted) than the first syllable. The phonetics does not account for this difference; two of the words moved front to mid/back ("balloon" and "tiger") and two of words moved from back/mid to front ("coffee" and "giraffe"), one iamb and one trochee in each set. For the most part, the values observed for F2 in the iambs are consistent with what would be expected based on the phonetic content (according to the collected formant charts of Kent and Read (2002)). However, for the trochees, the F2 at 20% value is higher (more fronted) than expected for the first syllable of trochees (across tasks), and lower (more backed) than expected in the second syllable of trochees (across tasks). This suggests that F2 may be a marker of lexical stress in trochees, with more fronting for stressed syllables and more backing for unstressed syllables. This is not observed in iambs. However, given the small sample size, this remains a suggestion for future research.

Limitations and Future Directions

Lexical Control of Positional Location in Phrase

While positional location effects are not explicitly observed in these results, they were not controlled for in the spontaneous speech task. In the list task, analysis tokens were always taken from the middle rather than beginning or the end of the list. However, the tokens in the spontaneous speech task were taken from wherever they were produced in an utterance. Any tokens produced in isolation or taken from the end of an utterance would likely show effects of phrase-final lengthening that could distort measures such as duration. In fact, the second syllables of iambs were produced with longer duration in isolated productions than in list production or spontaneous speech (Table 15), and the duration distinction across syllables was stronger in isolation than in list intonation (Table 13). We did not see the effects of final phrase lengthening in our spontaneous speech data, but tasks with stronger positional control would strengthen these findings.

Lip and Jaw Positioning for Consonants and Vowels

The target words were selected from a corpus because of their tendency to appear multiple times in the designed tasks, not necessarily because of phonemic balance. There is a benefit to using non-heteronymic target words because this represents more naturalistic speech. We are not usually trying to differentiate between noun phrases and noun compounds, or heteronymic noun-verb pairs, in everyday speech. However, the deliberate avoidance of heteronomy results in a lack of phonemic balance. With this sample we cannot rule out the effects of voiced vs. unvoiced consonants, plosives vs. fricatives, nasals, liquids, and overall placement of consonants and vowels alike. Each of these physical components of motor-speech production may have a significant effect or no effect on any of the dependent variables and should be systematically controlled for and examined to increase the level of confidence with which we can generalize from this data set.

Mean Pitch and Mean Intensity vs Min/Max

We chose to collect mean pitch and mean intensity data rather than min, max, and range because individual syllable contours in standard American English are not expected to have a significant intonation change across the syllable. The finding that the PVI of mean pitch was greater in trochees than iambs could be explained by the tendency of the second syllable in a declarative mode in standard American English to have a falling pitch. In iambs, the upward pitch deflection is likely significantly higher in the second (strong) syllable than the first (weak) syllable. However, the maximum downward pitch deflection could also be significantly lower in the second syllable because of a falling contour. It is therefore possible for the average contour to appear flat and equivalent with the first (weak) syllable. Because we did not collect full contour data, assertions about the use of pitch to mark lexical stress, particularly in iambs, are more limited.

Vocal Fry

It was noted anecdotally during analysis that some subjects frequently (though not necessarily consistently) used vocal fry. This necessitated the development of protocols to correct for pitch when this occurred. It is possible that the use of vocal fry, rather than being an inherent sign of dysfunction, could be another way of marking stress differences between syllables. If this is the case, unstressed syllables would be more likely than stressed syllables to be produced with vocal fry. Vocal fry is typically associated with both reduced pitch and reduced intensity, though it is sufficiently different from modal phonation that relying only on these two measures is unlikely to capture the use of this mode in lexical stress marking. Anecdotally, the samples analyzed in this data set included instances of fry across gender and group, with some participants demonstrating vocal fry across both syllables of target words. Future research could systematically explore the use of vocal fry as a prosodic marking strategy.

Formant 3 (and Higher)

As F1 appears to be a clear measure of lexical stress and there is evidence that F2 may play a role in the marking of position, higher formants may also be worth exploring to determine whether they also play a role in prosody, and perhaps even whether higher formants are affected by PD.

Conclusions

Ultimately, people with PD rely on the same cues as typical age- and sex-matched controls. Spontaneous speech tasks should be used to transfer skills to everyday communication, although isolated productions could be used to support early learning. Trochees and iambs are marked differently, thus, prosodic variation is more than learning to mark via one acoustic characteristic. Assessments, whether in a research or a clinical setting, ought to use naturalistic spontaneous speech tasks over tasks such as isolated words or lists of words in order to capture the most accurate picture of a person’s prosodic deficit.

TABLES

Table 5: Main Effects of Group: Means (standard error in parentheses)

Variable	F	*p*	Parkinson Disease	Control
Duration of Vowel	0.04	0.851	0.18 (0.004)	0.18 (0.003)
PVI of Duration of Vowel	0.06	0.813	0.67 (0.019)	0.66 (0.019)
Mean F0 of Vowel	16.76	<0.001*	148.52 (2.291)	135.32 (2.270)
PVI of F0 of Vowel	16.29	<0.001*	0.10 (0.012)	0.17 (0.012)
Mean Intensity of Vowel	2.62	0.106	58.34 (0.423)	59.31 (0.419)
PVI of Intensity of Vowel	0.28	0.600	0.05 (0.004)	0.05 (0.004)
Bark Scale F1 20% of Vowel	5.67	0.018*	4.60 (0.070)	4.84 (0.069)
Bark Scale F1 50% of Vowel	8.46	0.004*	4.65 (0.073)	4.95 (0.072)
Bark Scale F1 80% of Vowel	8.31	0.004*	4.21 (0.087)	4.57 (0.086)
Bark Scale F2 20% of Vowel	3.58	0.059	13.30 (0.136)	12.93 (0.135)
Bark Scale F2 50% of Vowel	1.10	0.295	13.55 (0.141)	13.34 (0.140)
Bark Scale F2 80% of Vowel	1.97	0.161	13.68 (0.155)	13.37 (0.153)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	0.45	0.504	1.35 (0.068)	1.41 (0.067)
Euclidean Distance of Vowel, F1-F2 (mid to end)	0.53	0.465	1.50 (0.064)	1.44 (0.063)

Table 6: Main Effects of Task: Means (standard error in parentheses)

Variable	F	*p*	Isolated	List	Map
Duration of Vowel	2.03	0.132	0.19 (0.004)	0.18 (0.004)	0.18 (0.004)
PVI of Duration of Vowel	2.36	0.097	0.71 (0.023)	0.65 (0.023)	0.65 (0.023)
Mean F0 of Vowel	0.95	0.388	141.66 (2.775)	139.33 (2.829)	144.77 (2.775)
PVI of F0 of Vowel	19.43	<0.001*	0.18 (0.014)	0.06 (0.014)	0.16 (0.014)
Mean Intensity of Vowel	0.27	0.760	59.10 (0.512)	58.56 (0.522)	58.81 (0.512)
PVI of Intensity of Vowel	3.63	0.028*	0.06 (0.005)	0.04 (0.005)	0.05 (0.005)
Bark Scale F1 20% of Vowel	0.76	0.469	4.67 (0.085)	4.98 (0.086)	4.81 (0.085)
Bark Scale F1 50% of Vowel	4.26	0.015*	4.65 (0.088)	4.74 (0.090)	5.00 (0.090)
Bark Scale F1 80% of Vowel	4.01	0.019*	4.21 (0.105)	4.33 (0.107)	4.62 (0.105)
Bark Scale F2 20% of Vowel	7.19	<0.001*	12.65 (0.165)	13.54 (0.168)	13.16 (0.165)
Bark Scale F2 50% of Vowel	1.98	0.139	13.17 (0.171)	13.63 (0.174)	13.53 (0.171)
Bark Scale F2 80% of Vowel	1.32	0.267	13.28 (0.187)	13.65 (0.191)	13.65 (0.187)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	0.01	0.991	1.39 (0.082)	1.37 (0.083)	1.38 (0.082)
Euclidean Distance of Vowel, F1-F2 (mid to end)	1.68	0.187	1.36 (0.077)	1.56 (0.078)	1.49 (0.077)

Table 7: Main Effects of Syllable Number: Means (standard error in parentheses)

Variable	F	*p*	First Syllable	Second Syllable
Duration of Vowel	379.53	<0.001*	0.13 (0.004)	0.23 (0.004)
Mean F0 of Vowel	0.40	0.528	140.90 (2.283)	142.94 (2.278)
Mean Intensity of Vowel	4.49	0.035*	59.46 (0.421)	58.20 (0.420)
Bark Scale F1 20% of Vowel	80.68	<0.001*	5.16 (0.070)	4.28 (0.070)
Bark Scale F1 50% of Vowel	75.78	<0.001*	5.24 (0.072)	4.35 (0.072)
Bark Scale F1 80% of Vowel	25.91	<0.001*	4.70 (0.086)	4.08 (0.086)
Bark Scale F2 20% of Vowel	74.39	<0.001*	12.29 (0.136)	13.94 (0.135)
Bark Scale F2 50% of Vowel	153.02	<0.001*	12.22 (0.140)	14.67 (0.140)
Bark Scale F2 80% of Vowel	80.28	<0.001*	12.55 (0.154)	14.50 (0.154)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	5.40	0.021*	1.27 (0.067)	1.49 (0.067)
Euclidean Distance of Vowel, F1-F2 (mid to end)	4.80	0.029*	1.57 (0.063)	1.37 (0.063)

Table 8: Main Effects of Stress Pattern: Means (standard error in parentheses)

Variable	F	*p*	Trochaic	Iambic
Duration of Vowel	13.69	<0.001*	0.17 (0.004)	0.19 (0.004)
PVI of Duration of Vowel	833.10	<0.001*	0.29 (0.019)	1.05 (0.019)
Mean F0 of Vowel	2.44	0.119	144.44 (2.283)	139.40 (2.278)
PVI of F0 of Vowel	43.70	<0.001*	0.19 (0.012)	0.08 (0.012)
Mean Intensity of Vowel	5.50	0.019*	58.13 (0.421)	59.52 (0.420)
PVI of Intensity of Vowel	40.22	<0.001*	0.07 (0.004)	0.03 (0.004)
Bark Scale F1 20% of Vowel	48.15	<0.001*	5.06 (0.070)	4.38 (0.070)
Bark Scale F1 50% of Vowel	15.36	<0.001*	5.00 (0.072)	4.60 (0.072)
Bark Scale F1 80% of Vowel	11.93	<0.001*	4.18 (0.086)	4.60 (0.086)
Bark Scale F2 20% of Vowel	3.20	0.074	13.29 (0.136)	12.94 (0.135)
Bark Scale F2 50% of Vowel	8.94	0.003*	13.74 (0.140)	13.15 (0.140)
Bark Scale F2 80% of Vowel	67.25	<0.001*	14.42 (0.154)	12.63 (0.154)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	15.76	<0.001*	1.19 (0.067)	1.57 (0.067)
Euclidean Distance of Vowel, F1-F2 (mid to end)	13.37	<0.001*	1.63 (0.063)	1.31 (0.063)

Table 9: Group x Task Interaction Effects: Means (standard error in parentheses)

Variable	F	*p*	Parkinson Disease: Isolated	Parkinson Disease: List	Parkinson Disease: Map	Control: Isolated	Control: List	Control: Map
Duration of Vowel	0.72	0.487	0.19 (0.006)	0.18 (0.006)	0.18 (0.006)	0.18 (0.006)	0.18 (0.006)	0.18 (0.006)
PVI of Duration of Vowel	1.00	0.368	0.72 (0.032)	0.67 (0.033)	0.63 (0.032)	0.70 (0.032)	0.62 (0.032)	0.67 (0.032)
Mean F0 of Vowel	0.86	0.422	149.07 (3.924)	148.04 (4.054)	148.47 (3.924)	134.26 (3.924)	130.63 (3.946)	141.07 (3.924)
PVI of F0 of Vowel	2.70	0.069	0.12 (0.020)	0.05 (0.021)	0.12 (0.020)	0.23 (0.020)	0.07 (0.020)	0.20 (0.020)
Mean Intensity of Vowel	0.74	0.478	59.12 (0.724)	57.72 (0.748)	58.20 (0.724)	59.09 (0.724)	59.41 (0.728)	59.42 (0.724)
PVI of Intensity of Vowel	1.38	0.253	0.05 (0.008)	0.04 (0.008)	0.06 (0.008)	0.07 (0.008)	0.04 (0.008)	0.05 (0.008)
Bark Scale F1 20% of Vowel	1.70	0.184	4.44 (0.120)	4.67 (0.124)	4.70 (0.120)	4.91 (0.120)	4.69 (0.121)	4.91 (0.120)
Bark Scale F1 50% of Vowel	1.10	0.333	4.40 (0.124)	4.67 (0.128)	4.88 (0.124)	4.90 (0.124)	4.82 (0.125)	5.12 (0.124)
Bark Scale F1 80% of Vowel	0.03	0.972	4.02 (0.149)	4.17 (0.154)	4.46 (0.149)	4.41 (0.149)	4.50 (0.149)	4.79 (0.149)
Bark Scale F2 20% of Vowel	0.96	0.385	12.65 (0.233)	13.86 (0.241)	13.38 (0.233)	12.64 (0.233)	13.21 (0.234)	12.95 (0.233)
Bark Scale F2 50% of Vowel	0.50	0.607	13.15 (0.241)	13.77 (0.249)	13.74 (0.241)	13.20 (0.241)	13.50 (0.243)	13.32 (0.241)
Bark Scale F2 80% of Vowel	0.26	0.773	13.33 (0.265)	13.83 (0.274)	13.88 (0.265)	13.23 (0.265)	13.48 (0.267)	13.41 (0.265)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	0.02	0.978	1.36 (0.116)	1.35 (0.120)	1.33 (0.116)	1.42 (0.116)	1.40 (0.116)	1.43 (0.116)
Euclidean Distance of Vowel, F1-F2 (mid to end)	0.81	0.445	1.36 (0.109)	1.67 (0.112)	1.47 (0.109)	1.35 (0.109)	1.44 (0.109)	1.51 (0.109)

Table 10: Group x Syllable Number Interaction Effects: Means (standard error in parentheses)

Variable	F	*p*	Parkinson Disease: First Syllable	Parkinson Disease: Second Syllable	Control: First Syllable	Control: Second Syllable
Duration of Vowel	1.58	0.209	0.13 (0.005)	0.23 (0.005)	0.14 (0.005)	0.23 (0.005)
Mean F0 of Vowel	0.43	0.510	148.57 (3.240)	148.48 (3.240)	133.24 (3.216)	137.40 (3.204)
Mean Intensity of Vowel	0.44	0.508	58.78 (0.60)	57.92 (0.598)	60.13 (0.593)	58.48 (0.59)
Bark Scale F1 20% of Vowel	2.33	0.128	4.97 (0.099)	4.24 (0.099)	5.35 (0.098)	4.32 (0.098)
Bark Scale F1 50% of Vowel	1.19	0.275	5.04 (0.103)	4.26 (0.103)	5.45 (0.102)	4.45 (0.101)
Bark Scale F1 80% of Vowel	0.00	0.993	4.53 (0.123)	3.90 (0.123)	4.88 (0.122)	4.26 (0.121)
Bark Scale F2 20% of Vowel	0.81	0.369	12.56 (0.192)	14.04 (0.192)	12.02 (0.191)	13.85 (0.190)
Bark Scale F2 50% of Vowel	3.17	0.076	12.50 (0.199)	14.60 (0.199)	11.94 (0.198)	14.75 (0.197)
Bark Scale F2 80% of Vowel	1.33	0.250	12.83 (0.219)	14.53 (0.219)	12.27 (0.217)	14.47 (0.216)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	0.01	0.936	1.24 (0.096)	1.46 (0.096)	1.299 (0.095)	1.53 (0.094)
Euclidean Distance of Vowel, F1-F2 (mid to end)	0.11	0.739	1.58 (0.090)	1.42 (0.090)	1.55 (0.089)	1.32 (0.089)

Table 11: Group x Stress Pattern Interaction Effects: Means (standard error in parentheses)

Variable	F	*p*	Parkinson Disease: Trochaic	Parkinson Disease: Iambic	Control: Trochaic	Control: Iambic
Duration of Vowel	0.01	0.920	0.17 (0.005)	0.19 (0.005)	0.17 (0.005)	0.19 (0.005)
PVI of Duration of Vowel	1.18	0.278	0.28 (0.027)	1.07 (0.026)	0.30 (0.026)	1.03 (0.026)
Mean F0 of Vowel	0.03	0.866	150.77 (3.253)	146.28 3.2274	138.11 (3.204)	132.53 (3.216)
PVI of F0 of Vowel	5.09	0.025*	0.14 (0.017)	0.06 (0.016)	0.24 (0.016)	0.09 (0.016)
Mean Intensity of Vowel	0.01	0.906	57.68 (0.600)	59.01 (0.595)	58.57 (0.591)	60.04 (0.593)
PVI of Intensity of Vowel	2.35	0.127	0.07 (0.006)	0.04 (0.006)	0.08 (0.006)	0.03 (0.006)
Bark Scale F1 20% of Vowel	0.06	0.812	4.93 (0.099)	4.27 (0.099)	5.19 (0.098)	4.48 (0.098)
Bark Scale F1 50% of Vowel	0.68	0.408	4.81 (0.103)	4.49 (0.102)	5.19 (0.101)	4.70 (0.102)
Bark Scale F1 80% of Vowel	2.23	0.136	3.91 (0.123)	4.52 (0.122)	4.45 (0.121)	4.69 (0.122)
Bark Scale F2 20% of Vowel	0.94	0.334	13.38 (0.193)	13.22 (0.192)	13.20 (0.190)	12.67 (0.191)
Bark Scale F2 50% of Vowel	2.13	0.145	13.70 (0.200)	13.40 (0.198)	13.78 (0.197)	12.90 (0.198)
Bark Scale F2 80% of Vowel	2.05	0.153	14.42 (0.220)	12.94 (0.218)	14.42 (0.216)	12.32 (0.217)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	0.02	0.892	1.17 (0.096)	1.53 (0.095)	1.22 (0.094)	1.61 (0.095)
Euclidean Distance of Vowel, F1-F2 (mid to end)	1.13	0.289	1.71 (0.090)	1.29 (0.089)	1.55 (0.089)	1.32 (0.089)

Table 12: Task x Syllable Number Interaction Effects: Means (standard error in parentheses)

Variable	F	*p*	Isolated: First Syllable	Isolated: Second Syllable	List: First Syllable	List: Second Syllable	Map: First Syllable	Map: Second Syllable
Duration of Vowel	3.22	0.041*	0.13 (0.006)	0.24 (0.006)	0.14 (0.006)	0.22 (0.006)	0.13 (0.006)	0.23 (0.006)
Mean F0 of Vowel	0.06	0.945	140.24 (3.924)	143.08 (3.924)	139.09 (4.011)	139.58 (3.990)	143.37 (3.924)	146.16 (3.924)
Mean Intensity of Vowel	0.25	0.775	60.03 (0.724)	58.18 (0.724)	59.00 (0.740)	58.13 (0.736)	59.34 (0.724)	58.28 (0.724)
Bark Scale F1 20% of Vowel	3.01	0.050	5.23 (0.120)	4.12 (0.120)	5.18 (0.123)	4.18 (0.122)	5.08 (0.120)	4.53 (0.120)
Bark Scale F1 50% of Vowel	0.28	0.756	5.10 (0.124)	4.20 (0.124)	5.23 (0.127)	4.26 (0.126)	5.39 (0.124)	4.61 (0.124)
Bark Scale F1 80% of Vowel	0.49	0.610	4.56 (0.149)	3.87 (0.149)	4.70 (0.152)	3.97 (0.151)	4.85 (0.149)	4.40 (0.149)
Bark Scale F2 20% of Vowel	1.07	0.344	11.82 (0.233)	13.48 (0.233)	12.88 (0.238)	14.19 (0.237)	12.17 (0.233)	14.16 (0.233)
Bark Scale F2 50% of Vowel	0.44	0.642	12.06 (0.241)	14.29 (0.241)	12.42 (0.247)	14.85 (0.245)	12.19 (0.241)	14.87 (0.241)
Bark Scale F2 80% of Vowel	0.07	0.929	12.25 (0.265)	14.30 (0.265)	12.73 (0.271)	14.58 (0.270)	12.67 (0.265)	14.62 (0.265)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	1.08	0.342	1.19 (0.116)	1.59 (0.116)	1.28 (0.118)	1.47 (0.118)	1.35 (0.116)	1.41 (0.116)
Euclidean Distance of Vowel, F1-F2 (mid to end)	0.38	0.687	1.44 (0.109)	1.28 (0.109)	1.62 (0.111)	1.49 (0.111)	1.64 (0.109)	1.34 (0.109)

Table 13: Task x Stress Pattern Interaction Effects: Means (standard error in parentheses)

Variable	F	*p*	Isolated: Trochaic	Isolated: Iambic	List: Trochaic	List: Iambic	Map: Trochaic	Map: Iambic
Duration of Vowel	3.94	0.020*	0.17 (0.006)	0.21 (0.006)	0.17 (0.006)	0.18 (0.006)	0.18 (0.006)	0.19 (0.006)
PVI of Duration of Vowel	7.86	<0.001*	0.26 (0.032)	1.16 (0.032)	0.33 (0.033)	0.96 (0.032)	0.27 (0.032)	1.03 (0.032)
Mean F0 of Vowel	0.25	0.782	144.56 (3.924)	138.77 (3.924)	143.01 (4.013)	135.66 (3.988)	145.75 (3.924)	143.79 (3.924)
PVI of F0 of Vowel	8.44	<0.001*	0.28 (0.020)	0.08 (0.012)	0.08 (0.020)	0.05 (0.020)	0.21 (0.020)	0.11 (0.020)
Mean Intensity of Vowel	1.37	0.254	58.11 (0.724)	60.10 (0.724)	58.57 (0.740)	58.56 (0.736)	57.71 (0.724)	59.91 (0.724)
PVI of Intensity of Vowel	2.41	0.092	0.09 (0.008)	0.03 (0.008)	0.06 (0.008)	0.03 (0.008)	0.07 (0.008)	0.04 (0.008)
Bark Scale F1 20% of Vowel	1.75	0.175	5.11 (0.120)	4.23 (0.120)	5.05 (0.123)	4.31 (0.122)	5.02 (0.120)	4.59 (0.120)
Bark Scale F1 50% of Vowel	1.07	0.345	4.92 (0.124)	4.37 (0.124)	4.97 (0.127)	4.52 (0.126)	5.10 (0.124)	4.90 (0.124)
Bark Scale F1 80% of Vowel	1.42	0.242	4.12 (0.149)	4.30 (0.149)	4.13 (0.152)	4.54 (0.151)	4.28 (0.149)	4.96 (0.149)
Bark Scale F2 20% of Vowel	2.97	0.052	13.13 (0.233)	12.16 (0.233)	13.64 (0.238)	13.43 (0.237)	13.09 (0.233)	13.24 (0.233)
Bark Scale F2 50% of Vowel	4.03	0.018*	13.86 (0.241)	12.49 (0.241)	13.78 (0.247)	13.49 (0.245)	13.59 (0.241)	13.48 (0.241)
Bark Scale F2 80% of Vowel	3.22	0.041*	14.56 (0.265)	11.99 (0.265)	14.36 (0.271)	12.95 (0.269)	14.34 (0.265)	12.96 (0.265)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	3.16	0.043*	1.35 (0.116)	1.43 (0.116)	1.04 (0.118)	1.71 (0.118)	1.19 (0.116)	1.57 (0.116)
Euclidean Distance of Vowel, F1-F2 (mid to end)	0.87	0.419	1.54 (0.109)	1.18 (0.109)	1.64 (0.111)	1.47 (0.111)	1.72 (0.109)	1.26 (0.109)

Table 14: Syllable Number x Stress Pattern Interaction Effects: Means (standard error in parentheses)

Variable	F	*p*	Trochaic: First Syllable (Strong)	Trochaic: Second Syllable (Weak)	Iambic: First Syllable (Weak)	Iambic: Second Syllable (Strong)
Duration of Vowel	481.29	<0.001*	0.18 (0.005)	0.17 (0.005)	0.09 (0.005)	0.29 (0.005)
Mean F0 of Vowel	0.40	0.528	144.44 (3.229)	144.44 (3.229)	137.37 (3.227)	141.44 (3.216)
Mean Intensity of Vowel	14.44	<0.001*	59.89 (0.595)	56.37 (0.596)	59.02 (0.595)	60.02 (0.593)
Bark Scale F1 20% of Vowel	243.57	<0.001*	6.27 (0.099)	4.05 (0.099)	3.85 (0.099)	4.70 (0.098)
Bark Scale F1 50% of Vowel	314.50	<0.001*	6.35 (0.102)	3.65 (0.102)	4.14 (0.102)	5.06 (0.102)
Bark Scale F1 80% of Vowel	166.09	<0.001*	5.28 (0.122)	4.43 (0.122)	3.08 (0.122)	5.08 (0.122)
Bark Scale F2 20% of Vowel	80.75	<0.001*	11.60 (0.192)	14.97 (0.192)	12.98 (0.192)	12.91 (0.191)
Bark Scale F2 50% of Vowel	13.14	<0.001*	12.16 (0.198)	15.33 (0.198)	12.28 (0.198)	14.02 (0.198)
Bark Scale F2 80% of Vowel	2.07	0.151	13.29 (0.218)	15.55 (0.218)	11.81 (0.218)	13.45 (0.217)
Euclidean Distance of Vowel, F1-F2 (beg to mid)	21.65	<0.001*	1.30 (0.095)	1.08 (0.095)	1.24 (0.095)	1.90 (0.095)
Euclidean Distance of Vowel, F1-F2 (mid to end)	51.31	<0.001*	2.05 (0.089)	1.21 (0.089)	1.80 (0.089)	1.53 (0.089)

Table 15: Task x Syllable Number x Stress Pattern Interaction Effects: Means (standard error in parentheses)

Variable	Task	F	*p*	Trochaic: First Syllable (Strong)	Trochaic: Second Syllable (Weak)	Iambic: First Syllable (Weak)	Iambic: Second Syllable (Strong)
Duration of Vowel	Isolated	5.12	0.006*	0.18 (0.009)	0.16 (0.009)	0.09 (0.009)	0.33 (0.009)
	List			0.18 (0.009)	0.16 (0.009)	0.09 (0.009)	0.27 (0.009)
	Map			0.18 (0.009)	0.18 (0.009)	0.09 (0.009)	0.28 (0.009)
Mean F0 of Vowel	Isolated	0.15	0.858	143.41 (5.550)	145.70 (5.550)	137.07 (5.550)	140.46 (5.550)
	List			143.28 (5.675)	142.74 (5.675)	134.90 (5.669)	136.42 (5.610)
	Map			146.63 (5.550)	144.87 (5.550)	140.12 (5.550)	147.45 (5.550)
Mean Intensity of Vowel	Isolated	0.12	0.887	60.28 (1.024)	55.93 (1.024)	59.78 (1.024)	60.43 (1.024)
	List			59.93 (1.047)	57.20 (1.047)	58.08 (1.047)	59.05 (1.035)
	Map			59.46 (1.024)	55.97 (1.024)	59.21 (1.024)	60.60 (1.024)
Bark Scale F1 20% of Vowel	Isolated	1.32	0.267	6.44 (0.170)	3.78 (0.170)	4.01 (0.170)	4.46 (0.170)
	List			6.21 (0.173)	3.89 (0.173)	4.15 (0.173)	4.48 (0.173)
	Map			6.16 (0.170)	3.89 (0.170)	4.00 (0.170)	5.17 (0.170)
Bark Scale F1 50% of Vowel	Isolated	0.22	0.805	6.24 (0.176)	3.61 (0.176)	3.96 (0.176)	4.79 (0.176)
	List			6.36 (0.180)	3.58 (0.180)	4.10 (0.180)	4.93 (0.178)
	Map			6.44 (0.176)	4.35 (0.176)	3.76 (0.176)	5.45 (0.176)
Bark Scale F1 80% of Vowel	Isolated	0.22	0.799	5.23 (0.210)	3.02 (0.210)	3.89 (0.210)	4.72 (0.210)
	List			5.34 (0.215)	2.92 (0.215)	4.05 (0.215)	5.02 (0.212)
	Map			5.27 (0.210)	3.30 (0.210)	4.43 (0.210)	5.50 (0.210)
Bark Scale F2 20% of Vowel	Isolated	0.26	0.772	11.39 (0.330)	14.87 (0.330)	12.24 (0.330)	12.09 (0.330)
	List			12.08 (0.337)	15.20 (0.337)	13.69 (0.337)	13.17 (0.333)
	Map			11.33 (0.330)	14.85 (0.330)	13.01 (0.330)	13.47 (0.330)
Bark Scale F2 50% of Vowel	Isolated	0.23	0.791	12.34 (0.341)	15.38 (0.341)	11.77 (0.341)	13.20 (0.341)
	List			12.15 (0.349)	15.41 (0.349)	12.68 (0.349)	14.30 (0.345)
	Map			11.98 (0.341)	15.19 (0.341)	12.40 (0.341)	14.56 (0.341)
Bark Scale F2 80% of Vowel	Isolated	0.40	0.668	13.44 (0.375)	15.67 (0.375)	11.05 (0.375)	12.94 (0.375)
	List			13.14 (0.383)	15.58 (0.383)	12.32 (0.383)	13.59 (0.380)
	Map			13.28 (0.375)	15.39 (0.375)	12.07 (0.375)	13.84 (0.375)
Euclid. Distance Vowel, F1-F2 (beg to mid)	Isolated	0.04	0.965	1.38 (0.164)	1.32 (0.164)	1.00 (0.164)	1.87 (0.164)
	List			1.14 (0.167)	0.93 (0.167)	1.41 (0.167)	2.01 (0.165)
	Map			1.39 (0.164)	1.31 (0.164)	1.00 (0.164)	1.83 (0.164)
Euclidean Distance of Vowel, F1-F2 (mid to end)	Isolated	0.64	0.527	1.90 (0.154)	1.17 (0.154)	0.98 (0.154)	1.39 (0.154)
	List			1.99 (0.157)	1.29 (0.157)	1.25 (0.157)	1.69 (0.156)
	Map			2.26 (0.154)	1.18 (0.154)	1.02 (0.154)	1.50 (0.154)

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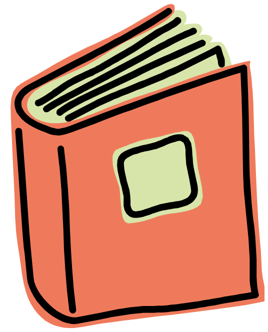
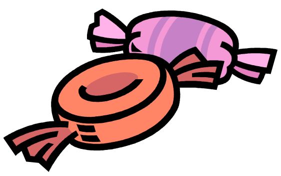
APPENDIX A. PICTURE LISTING TASK

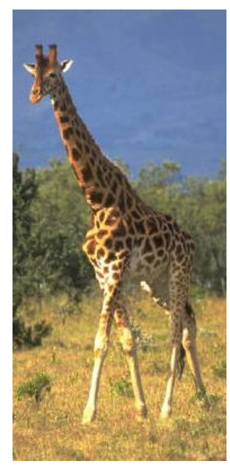






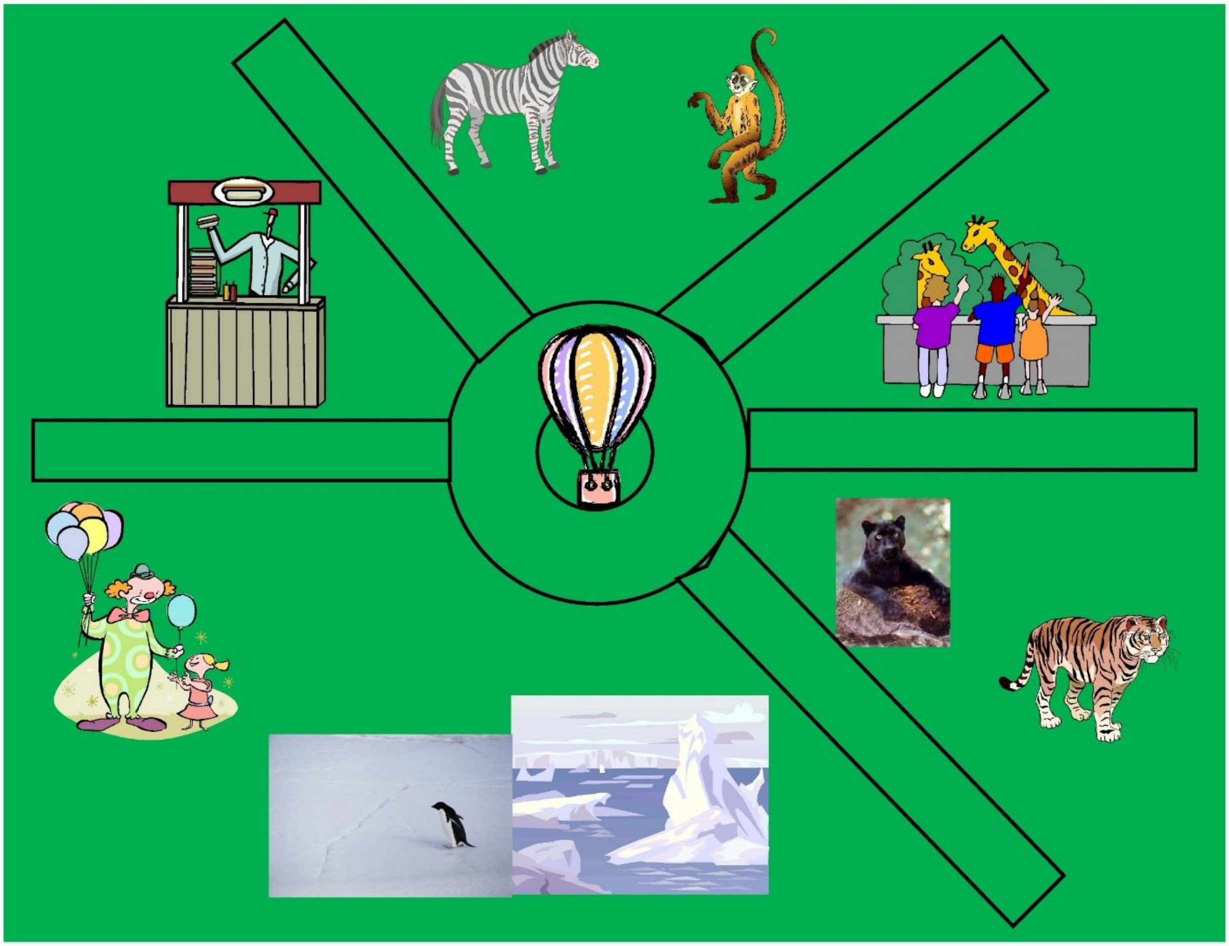







APPENDIX B. MAP TASK: STREETS

APPENDIX C. MAP TASK: ZOO



APPENDIX D: VOWEL QUADRILATERALS BY GENDER AND TASK

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