ACOUSTIC MEASUREMENTS OF CLEAR SPEECH CUE FADE
IN ADULTS WITH IDIOPATHIC PARKINSON DISEASE

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The purpose of this study was to examine the potential fade in the effects of a clear speech cue on selected acoustic features of Parkinsonian speech as participants read a passage. Participants were 12 adults with idiopathic Parkinson disease (mean age = 73 years), reading a passage with the instructions to “Produce the items as clearly as possible, as if I am having trouble hearing or understanding you.” The effects of clear speech were measured using speech rate, articulation rate, fundamental frequency, variation in fundamental frequency, intensity difference between stressed and unstressed syllables, and intensity change from the beginning of the passage to the end. Results indicated that the clear speech cue broke down early in the reading as suggested by an increase in speech and articulation rates, a decrease in fundamental frequency standard deviation, and an overall decrease in intensity. There was a negligible decrease in average fundamental frequency and the maintenance of the difference between intensity between the two syllables of “rainbow” near the beginning and end of the reading. These findings suggest that some prosodic aspects (laryngeal, short-term respiratory) may reflect maintenance of the clear speech cue or general stability, but more global aspects of speech over time (long-term articulation, long-term respiratory control) suggest the lack of maintaining the clear speech cue or relatively little response to the clear speech cue.
This thesis is dedicated to all of the amazing people who have ever encouraged curiosity,

provided their own insight, or inspired me to discover my own answers.
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I would like to thank my advisor, Dr. Ronald Scherer, for consistently being encouraging and teaching me the importance of research. I would also like to thank my committee members, Dr. Goberman for providing background information about Parkinson Disease as well as the samples used in this project, and Dr. Whitfield for assistance with statistics and writing. Again, huge thanks to my entire committee for providing guidance and giving helpful suggestions relating to my project.
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INTRODUCTION

Parkinson Disease

Idiopathic Parkinson Disease (PD) is a neurological disorder that affects more than 1 million people in North America (Lang & Lozano, 1998). Parkinson disease was first written about in 1817, and was described as a “shaking palsy” by James Parkinson (Parkinson, 1817). Since 1817 there has been a large body of research looking into the etiology and symptomology of PD. Currently, the etiology of PD is unknown. There is research supporting the possibility of age, genetic components, and family history as precursors to PD diagnosis (Lang & Lozano, 1998). According to Thomas and Beal (2007), there is most likely a genetic predisposition for PD, which in combination with certain environmental conditions may lead to the development of PD. Though there are many theories of the etiology of PD, there is no concrete evidence of one single cause.

PD is a neurological disorder that affects motor neuronal function in adults. Parkinson Disease directly affects the neurons in the substantia nigra that produce the multi-functional chemical dopamine (Brodal, 1998; Kent, Kent, Weismer, Martin, Sufit, Brooks, & Rosenbek, 1998; Lang & Lozano, 1998). The reduction of dopamine production in the brain manifests as change in motor control (Brodal, 1998; Lang & Lozano, 1998; Wong et al. 2014). The decrease in dopamine production caused by PD leads to changes in muscle movements and tremor (uncontrolled shaking of appendages that is more pronounced at rest). The diminishing amount of dopamine also causes rigidity (an increase in muscle tone), akinesia (difficulty with initiation of movement), and bradykinesia (slow movement following initiation of movement; Brodal, 1998; Lang & Lozano, 1998).
Changes caused by the reduction of dopamine affect movements such as walking, postural reflexes, dexterity of limbs, chewing, swallowing, and speaking (Meissner et al., 2011; Wong et al., 2014). Rigidity affects the ability to initiate and sustain fluid movement and can cause muscles to feel tight, or resist full range of motion (Lang & Lozano, 1998). Tremor typically begins unilaterally but then moves to both sides of the body and becomes more noticeable as PD progresses (Brodal, 1998; Lang & Lozano, 1998). Parkinson Disease directly affects movement but other impairments often co-occur with PD. Cognitive impairments such as dementia, motoric and physical fatigue, depression, anxiety, and sleep disturbances often co-occur with the physical changes of PD (Meissner et al., 2011; Wong et al., 2014).

Currently, the most effective treatment for PD is levodopa-based medicine. Levodopa is a precursor of dopamine and works to increase dopamine levels in the brain (Brodal, 1998). The treatment is effective for the management of symptoms, particularly rigidity and bradykinesia (Brodal, 1998). Though levodopa works to decrease the effect of symptoms, it does not change the course or progression of the disease (Brodal, 1998). Other treatments for PD include a wide variety of other pharmacological treatments, physical stimulation, deep brain stimulation, brain lesioning, and relatively controversial embryonic cell transplant (Brodal, 1998; Goberman & Coelho, 2002; Meissner et al., 2011).

**PD Effects on Speech**

As noted, the effect of Parkinson disease on muscle contraction and structural movement in adults is a relatively noticeable feature of the disease. Due to the negative impact PD has on muscle control, the speech characteristics of adults with PD are often altered (Love & Webb, 1992). The symptom most commonly associated with PD is hypokinetic dysarthria. Hypokinetic dysarthria is characterized by reduced amplitude of structural movement. Perceptually, the
characteristics of hypokineti
cubic dysarthria are apparent in deviations in pitch, loudness, respiratory
support, prosody, and articulation. In adults with PD, speech is often perceived as mono-pitched,
with mono-loudness, reduced prosodic stress, imprecise consonant articulation, linguistically
inappropriate pauses, rushes in timing of speech, and breathy harsh voice quality (Darley,

PD affects muscles of the respiratory system as well as the articulatory system
(Logemann, Fisher, Boshes, & Blonksy, 1978; Ludlow & Bassich, 1984). Rigidity of respiratory
muscles causes a decrease in the number of syllables per inhalation and overall shorter breath
groups (Solomon & Hixon, 1993). The rigidity of muscles of respiration also causes a reduction
in regulation of airflow and pressure relative to intensity (Ramig, Countryman, Thompson, &
Horii, 1995). Solomon and Hixon (1993) noted that the impact of reducing respiratory support
was most evident in reading, prolongation of vowels, and monologues. It was also noted that
overall intensity decreased, along with reduced intensity maintenance with or without external
cues (Ho, Iansek, & Bradshaw, 2001; Ho, Bradshaw, Iansek, & Alfredson, 1999; Holmes, Oates,
Phyland, & Hughes, 2000). Along with reduction of intensity, fundamental frequency of the
speaker is typically higher, again due to the rigidity of muscles, specifically in the larynx
(Canter, 1963; Doyle, Raade, St. Pierre, & Desai, 1995; Hertrich & Ackermann, 1995; Holmes,
Oates, Phyland, & Hughes, 2000).

A common articulatory feature of Parkinsonian speech is imprecise stop consonant
production due to poor tongue elevation not providing enough constriction to produce the stop
burst (Canter, 1965b; Weismer, 1984). Another articulatory feature of PD speech is poor
coordination of articulation with phonation, often perceived as an error of voicing in connected
speech (Canter, 1965; Weismer, 1984). Changes in structural movement speed prolong formant
transitions due to the decreased speed of articulator movement (Connor, Ludlow, & Schulz, 1989). The F2 transition has also been found to be flatter in sentence reading (Flint, Black, Campbell-Taylor, Gailey, & Levinton, 1992). The overall effect that PD has on speech has been noted to cause an overall decrease in intelligibility and prosody.

**Clear Speech**

Clear speech is a speaking style that provides perceptual benefits, such as increased intelligibility, to a variety of listeners and within a variety of listening environments. Clear speech has been found to be independent of both listener factors as well as speaker factors (Picheny, Durlach, & Braida, 1985). Uchanski (2005) broke down how to produce clear speech as “(1) articulate all phonemes precisely and accurately, (2) slow one’s speech rate just a bit, (3) pause slightly between phrases and thoughts, and (4) modestly increase vocal volume” (p. 217). In other studies, clear speech is cued using a variety of directions, some as simple as “speak louder” (Dromey, 2000). Despite the variations in cues, several studies suggest that clear speech manifests as increased intelligibility of speech.

Characteristics of clear speech have been identified through a large body of research. According to Picheny, Durlach, & Braida (1986), acoustically, clear speech is characterized by an increase in mean fundamental frequency, a greater variability of fundamental frequency, and a 5 to 8 dB increase in intensity in comparison to conversational speech. Vowel formant frequencies are closer to target values in clear speech than in conversational speech (Bradlow et al., 2003; Picheny et al., 1986). Clear speech is also characterized by an increase in the number of pauses and in the duration of pauses, as well as decreased articulation rates (Bradlow et al., 2003; Krause & Braida, 2002; Picheny et al., 1986). The contribution of these characteristics is what improves the intelligibility of speakers using clear speech.
Clear Speech and Parkinson Disease

Because of the intelligibility benefit associated with clear speech production, compensatory clear speech adjustments to speaking style may be used in a variety of contexts. Clear speech is commonly used as behavioral speech compensation to improve intelligibility in speakers with dysarthria (Hustard & Weismer, 2007). Clear speech is typically used as a cue to remind patients with dysarthria to use appropriate respiratory support, clear articulation, and a decreased speaking rate (Uchanski, 2005). As noted from the literature, dysarthria is a common feature of speech produced by adults with PD. The use of clear speech has been observed in patients with PD as a way to improve the acoustic features of speech and improve intelligibility overall (Dromey, 2000; Hustard & Weismer, 2007).

A benefit of the clear speech cue, in comparison to other cue-based therapy, is that it requires a simple cue. The single cue “speak clearly” requires a smaller cognitive load than remembering more complex cues (Dromey, 2000). There is very little research that examines how long the cue lasts in connected speech. The effectiveness of visual and verbal cues has been researched in the improvement of gait with patients with PD in physical therapy, and the research supports the use of verbal cues in physical therapy (McIntosh, Brown, Rice, & Thaut, 1997; Morris, Iansek, Matyas, & Summers, 1996; Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004). The lasting effect of a verbal cue on gait has been minimally researched in the physical therapy research, and even less so for speech improvements.

The focus of the research here is the acoustic characteristics of a clear speech request for patients with PD. If a patient is asked to speak with clear speech, will clear speech acoustic effects be present and last throughout a reading? The purpose of this study was to determine if there is a change in the acoustic effects of speech as participants read a passage after requesting
them to speak with clear speech. A “fade” or change in clear speech cue effects would be evident through changes in values of selected acoustic measures toward values associated with less clear speech.
METHODS

Participants

Six adult females and six adult males with PD participated in this study. The participants’ ages ranged from 55-84 years, with a mean age of 73 years. All participants had been diagnosed with idiopathic PD by a neurologist and all participants were receiving symptom-reducing medication. The patients were recorded prior to the design of the current study. That is, the recordings used in the present study had already been obtained in an earlier study.

Protocol

Participants were recorded during a visit to their neurologist. All recordings took place within a 15-minute recording session in a quiet room using a high quality microphone (Shure Model SM58) coupled to a portable digital audio recorder (Sony PCM-M1; sampling rate 44 kHz). After completing the informed consent process, participants were asked to complete an initial task which was the production of several consonant + vowel + consonant words embedded within a phrase. They then read the first paragraph of the Rainbow Passage (Fairbanks, 1960), and then complete a third task, a 2-minute monologue. Following the first set of the three tasks, the participants were instructed to repeat the tasks but with the added instruction to: “Produce the items as clearly as possible, as if I am having trouble hearing or understanding you.” This direction for clear speech was given at the beginning of the protocol and at the beginning of the reading task. Also, if the participants asked for more information regarding the production of clear speech, the directions were repeated and they were instructed to do whatever they felt would make them more clear. The mouth to microphone distance was a constant 15 centimeters during all recordings.
Acoustic Measures

Acoustic measurements were completed using Praat, which allows for digital recording, storage, analysis, and editing of acoustic samples. In order to obtain a progression of measurement values, each of the recordings of the Rainbow Passage was broken up into five segments of twenty-five syllables each (the fifth segment had 26 syllables). Measurements were obtained for the following five segments: (1) “When sunlight strikes rain drops in the air, they act like a prism and form a rainbow. The rainbow is a”; (2) “division of white light into many beautiful colors. These take the shape of a long round arch with”; (3) “its path high above and its two ends apparently beyond the horizon. There is according to”; (4) “legend a boiling pot of gold at one end. People look but no one ever finds it. When a man looks”; (5) “for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.” The specific acoustic measurements examined in the present study are discussed below. It is noted that there are potentially two natural pauses within segment 1, one in segment 2, two in segment 3, three in segment 4, and one in segment 5.

Speech Rate

“Speech rate” was calculated by counting the number of syllables within a segment, and then dividing that number by the duration of that segment. This provided a rate of syllables per second (syl/s). Speech rate included all portions of connected speech including pauses, disfluencies, and revisions. The speech rate was calculated on a range of 23 to 27 syllables for each of the five segments per participant. Time was rounded to the nearest thousandth of a second. A repetition of a syllable, related to a disfluency, was counted as an additional syllable. When reading the passage, if a participant omitted a word or syllable, the speech rate was calculated using the number of syllables produced. The hypothesis was that speech rate would
remain constant across the five speech segments because the speaker would maintain the clear speech characteristics self-established at the beginning of the reading following the clear speech request (cue).

**Articulation Rate**

“Articulation rate” measured the rate of speech for each participant with the exclusion of pauses. All pauses greater than 50 ms and not associated with a stop closure were removed from the sample (Goberman, Coelho, & Robb, 2005; Goberman & Elmer, 2005). Prior to removal, pauses in each sample were viewed using Praat in two-second intervals and double-checked by listening to the sample, to determine if a pause was present. After all of the pauses were removed, the articulation rate was calculated for each of the five segments per participant. For the calculation, the number of syllables was divided by the duration of the sample with pauses removed to determine a syllable per second (syl/s) articulation rate. Disfluencies were included in this calculation. Time was rounded to the nearest thousandth of a second. It was hypothesized that the articulation rate would remain the same across the five speech segments because the speaker would maintain clear speech characteristics throughout the entire passage.

**Percent Pause Time**

The percent pause time was calculated using the expression: 100 x [(total time – articulation time)/total time], where the total time is the duration from the onset to the offset of each segment prior to pause removals, and articulation time is the duration remaining after the removal of pauses. A percent pause time was calculated for each of the five segments of the Rainbow Passage. It was hypothesized that the percent pause time would remain the same across
the five speech segments because the speaker would maintain clear speech characteristics throughout the entire passage.

**Fundamental Frequency**

The fundamental frequency ($F_o$) was calculated throughout each of the five segments of the Rainbow Passage. The Praat setting “show pitch” was used to identify the $F_o$ values for the five segments. Praat’s “pitch listing” was extracted, outliers of very low or absent frequency value were removed, and an average $F_o$ and standard deviation were calculated. Frequencies removed included pitch listing values due to sub-harmonics, glottal fry, or voice quality for which the fundamental frequency was not obtainable. A small portion of the pitch listings was removed (an estimated <5%). $F_o$ was rounded to the nearest one-thousandth Hertz.

The pitch listing that was extracted from Praat was also graphed to determine the linear slope of the change in $F_o$ from the beginning of the passage to the end (across all 5 segments). The frequency at the beginning of the linear fit was compared to the frequency at the end of the linear fit. This measure was also obtained between the average frequency for segment one and the average frequency for segment five. All measurements of $F_o$ were converted into semitones to better represent $F_o$ perceptually and with reduced gender bias. To convert to semitones, the following formula was used: $n(ST)=39.86*\text{LOG}(F_o/65.406)$, where the referent frequency was 65.406 Hz (C2 on the piano). It was hypothesized that the various $F_o$ measures would remain constant over the five speech segments because the speaker would maintain clear speech characteristics throughout the entire passage.

**Variation in Fundamental Frequency**

The variation in $F_o$ throughout the passage was calculated for each of the five segments in
the passage. The variation was calculated in two ways: (1) the coefficient of variation (SD/Mean) using the units in Hz for each of the segments, and (2) the standard deviation in ST. It was hypothesized that the two fundamental frequency variation measures would not change across the five speech segments because the speaker would maintain clear speech characteristics throughout the entire passage.

**Intensity and Intensity Difference**

The difference in maximum intensity between the stressed (first) and unstressed (second) syllable of the multisyllabic word “rainbow” was obtained using the intensity display within Praat. The word rainbow was repeated three times during the passage. The intensity measure was taken from the first “rainbow” in the first half of the passage and the last “rainbow” in the second half of the passage. Using the “show intensity” option on Praat, the maximum intensity during both syllables of the two “rainbow” utterances were obtained using the cursor and visual selection. The intensity difference in dB between the stressed (rain) and the unstressed (bow) syllables at the beginning of the passage, was compared with the intensity difference at the end of the passage. The intensity difference between the first instance of the first syllable “rain” and the last instance of the first syllable “rain” (as well as the first and last instance of the word “bow”) was also calculated to determine if the overall speaking intensity decreased from the beginning of the passage to the end. It was hypothesized that there would be no change in intensity differences of stressed and unstressed syllables over the speech sample, and that the overall speaking intensity would remain the same, because of the maintenance of the clear speech cue.
Statistics

To examine the change in articulation rate, speech rate, and percent pause time over the five segments, a 2 x 5 Multivariate Analysis of Variance (MANOVA) was completed using the speech rate measure, the articulation rate measure, and the percent pause time measure. For this analysis, sex and segment were independent variables. To examine the change in fundamental frequency from the beginning of the passage to the end, a 2 x 2 repeated-measures Multivariate Analysis of Variance (MANOVA) was completed using both the fundamental frequency measures from the beginning and end of the passage as well as the average of segment 1 and of segment 5. For this analysis, sex and segment were the independent variables. To examine the relationship of intensity difference at the beginning and at the end of the passage, an Analysis of Variance (ANOVA) was completed using intensity difference at the beginning of the passage and at the end of the passage. For this analysis, sex and segment were independent variables. To examine the relationship of $F_o$ coefficient of variation, and standard deviation of semitone measures, an ANOVA was completed. The independent variables for this analysis were sex and segment. Post-hoc $t$-tests were completed as necessary and a Bonferroni correction was used.
RESULTS

Articulation

Multivariate results of the repeated-measures MANOVA that included speech rate, articulation rate, and percent pause, revealed no effect of Sex, $F(3,8)=2.532; \ p=.130; \ \eta^2=0.487$, but a main effect of segment, $F(12,120)=9.137; \ p<0.001; \ \eta^2=0.477$. The Segment by Sex interaction effect was also not significant, $F(12,120)=.756; \ p=0.694; \ \eta^2=0.070$.

Speech Rate.

The speech rate measurements for the group of twelve participants demonstrated that average speech rate changed through the progression of segments (Figure 1). The first segment average speech rate was 3.53 syl/s. As time progressed, the average speech rate increased for segment two (3.71 syl/s) and three (3.9 syl/s), then decreased to 3.6 syl/s for segment four, and then was maximum for segment five (4.32 syl/s). Thus, the trend was to increase syllable rate as the participants read through the passage, except for segment four. Univariate ANOVA results for average speech rate revealed a linear main effect of segment number, $F(1,10)=37.406; \ p<.001; \ \eta^2=0.789$, and no effect of Sex, $F(1,10)=.040; \ p=0.845; \ \eta^2=0.004$. The Segment by Sex interaction effect was not significant $F(4,40)=.320; \ p=.863; \ \eta^2=0.31$. The results for speech rate do not support the hypothesis that speech rate would remain constant across segments. The speech rate increased 22% (0.79 syl/s) from segment 1 to segment 5. The speech rates for all subjects are shown in individual figures in Appendix A.
Articulation Rate.

Composite average measures for the group of twelve participants’ articulation rates follow a similar trend to speech rate. As the passage progressed, the articulation rate increased (Figure 2). The first articulation rate segment was 3.95 syl/s. The remaining segments rose monotonically in value except for segment 3, which was relatively high (4.27, 4.66, 4.53, and 4.68 syl/s, respectively, for segments 2 through 5).

Univariate results of the repeated-measures Analysis of Variance (ANOVA) for average articulation rate revealed a linear main effect of segment number, $F(1,10)=52.458; p<0.001; \eta^2=0.84$, and no effect of Sex, $F(1,10)=.926; p=0.359; \eta^2=0.085$. The Segment by Sex interaction effect was not significant, $F(1,10)=.183; p=0.678; \eta^2=0.018$. The results for articulation rate do not support the hypothesis that articulation rate would remain constant across segments. The articulation rate increased by 18% (0.73 syl/s) between the first and last segment of the passage. Articulation rates are shown for individuals in Appendix B.
Average Articulation Rate

![Graph showing average articulation rate over segments.](image)

*y = 0.1734x + 3.8968
R^2 = 0.77737*

**Figure 2. Average Articulation Rate for all Participants.** The figure shows the average articulation rate in syl/s for each segment of the reading passage. Articulation rate was calculated after all pauses of 50 ms or longer were removed from the passage. The figure shows a linear trend in the change of articulation rate over the segments, suggesting that the clear speech cue faded across the segments.

**Percent Pause Time.**

The average percent pause time for the composite data demonstrated a change in percent pause time across segments. The changes in pause time did not follow a consistent trend (**Figure 3**). The percentages monotonically increased for segments 1-4 and then decreased for segment 5 (10.67%, 13.02%, 15.82%, 21.26%, and 7.96%, respectively).

Results of the repeated measures ANOVA for percent pause time revealed that unlike articulation rate, there was no linear trend across segments, \( F(1,10)=0.684; p=0.428; \eta^2=0.018 \). However, there was a significant main effect of segment, \( F(4,40)=15.635; p<0.001; \eta^2=0.61 \). Therefore, 10 post-hoc t-tests were completed to determine which segments were statistically different. A Bonferroni correction was used to control for multiple comparisons \((\alpha=0.05/10=0.005)\). Post-hoc results revealed significant differences between segment 1 and...
segment 4, \( t(11)=2.219; p=0.001 \), segment 2 and segment 4, \( t(11)=2.219; p=0.002 \), segment 3 and segment 5, \( t(11)=2.219; p=0.001 \), and segment 4 and segment 5, \( t(11)=2.219; p=0.001 \). All other comparisons were not statistically significant \((p>0.005\) for all pairs). The results for percent pause time do not support the hypothesis that percent pause time would remain constant across the reading. Also, it is pointed out that percent pause for segment 4 was approximately double that of segment 1. Refer to the Appendix C for percent pause time graphs for individual participants.

Figure 3. Average Percent Pause Time for all Participants. The figure shows the average percent pause time for each segment of the reading passage. Percent pause time was calculated after all pauses of 50 ms or longer were removed from the sample. The percentage was calculated using the expression \( 100 \times \frac{(total\ time - articulation\ time)}{total\ time} \). The figure shows a linear trend in the change of articulation rate over the first four segments, with segment 5 being the lowest percentage of pause time.

Fundamental Frequency

Multivariate results for the \( F_0 \) measures revealed a main effect of Segment, 
\[
F(2,9)=12.675; p<0.002; \eta^2=0.738,
\] and a main effect of Sex, \( F(2,9)=15.117; p<0.001; \eta^2=0.771.\)
There was no significant Segment by Sex interaction, $F(2,9)=.242; p=0.790; \eta^2=0.051$. The composite measurements demonstrated that average fundamental frequency changed throughout the entire passage (Figure 4). The fundamental frequency results are reported in semitones. The changes in fundamental frequency were observed by examining the frequency (in STs) at the beginning of the passage and at the end (that is, the value corresponding to the earliest-time point of the overall linear fit and the latest-time point of the overall linear fit), as well as the average fundamental frequency (in STs) of segment one compared to the average fundamental frequency (in STs) of segment five. The use of semitones to explain the difference in $F_o$ is important because the listener perceives pitch essentially logarithmically. Figure 4 shows both $F_o$ difference measures for each of the 12 participants. It is noted that all differences were positive, indicating a consistent decrease between the first and last value.

**Beginning of Passage to End of Passage.**

Results of the repeated-measures ANOVA for fundamental frequency comparing the beginning and end of the passage revealed a main effect of segment, $F(1,10)=28.037; p<0.001; \eta^2=0.737$, and an effect of Sex, $F(1,10)=33.586; p<0.001; \eta^2=0.771$. The Segment by Sex interaction effect was not significant, $F(1,10)=0.252; p=0.627; \eta^2=0.025$.

**Segment 1 to Segment 5.**

Results of the repeated-measures ANOVA for fundamental frequency comparing the average fundamental frequency for the first segment and the last segment revealed a main effect of Segment, $F(1,10)=12.445; p<0.005; \eta^2=0.554$, and an effect of Sex, $F(1,10)=32.861; p<0.001; \eta^2=0.767$. The Segment by Sex interaction effect was not significant, $F(1,10)<0.001; p=0.987; \eta^2<0.001$. The average $F_o$ for segment 1 was 15.33 ST and segment 5, 14.25 ST, a difference of
1.08 ST. The largest difference that occurred between the first segment and the last segment occurred for participant PD16, with a difference of 2.36 semitones.

The results for fundamental frequency did not support the hypothesis that fundamental frequency would not change over time. Although the change was consistent and statistically significant, the decrease of only approximately 1 ST does not appear to be a meaningful change given the wide variability of $F_o$ change during the readings (seen in the individual $F_o$ traces in Appendix D).

![Figure 4: Difference in Fundamental Frequency from Passage Start to End](image)

Figure 4. Difference in Fundamental Frequency from Passage Start to End. This figure shows the difference in fundamental frequency (in semitones) from the beginning of the passage to the end of the passage. Two measures are represented in this figure, the beginning and end of the passage according to the linear fit line across the entire recording, and the average $F_o$ for the first segment (1 of 5) and the last segment (5 of 5).
Coefficient of Variation of $F_o$ and Standard Deviation

Results of the repeated-measures MANOVA that included $F_o$ coefficient of variation as the combined dependent variable revealed a main effect of segment, $F(3,8)=12.234; p<0.032; \eta^2=0.970$, and a main effect of sex, $F(2,9)=4.617; p<0.042; \eta^2=0.506$. The Segment by Sex interaction effect was not significant, $F(3,8)=2.807; p<0.214; \eta^2=0.882$. Further examination of the univariate results for the $F_o$ coefficient of variation revealed a linear main effect of segment, $F(1,10)=0.22.179; p<0.001; \eta^2=0.689$, and no effect of Sex, $F(1,10)=.035; p=0.856; \eta^2=0.003$. The Segment by Sex interaction effect was not significant, $F(4,40)=1.896; p=0.130; \eta^2=0.159$. In general, as Figure 5 shows, the coefficient of variation was highest for segment 1, lowest for segment 5, and varied between 1 and 5. The results indicate that the variation of $F_o$ around the mean was least for the final segment.

![Coefficient of Variation for Fo](image)

**Figure 5.** Coefficient of Variation for Fundamental Frequency.

Results of the repeated-measures ANOVA for $F_o$ standard deviation of ST revealed a linear main effect of segment, $F(1,10)=44.150; p<0.001; \eta^2=0.815$, and no effect of Sex,
$F(1,10)=.410; p=0.536; \eta^2=0.039$. The Segment by Sex interaction effect was not significant, $F(4,40)=1.272; p=0.297; \eta^2=0.113$. This demonstrates that the variance (standard deviation) in $F_0$ decreased from the beginning of the passage to the end.

![Figure 6. Standard Deviation in ST for Fo](image)

**Figure 6. Standard Deviation in Semitones for Fundamental Frequency.** This figure shows the variation in $F_0$ as measured in semitones by segment and by gender. The figure shows a decreasing trend across segments.

**Intensity**

**Differences in Stressed and Unstressed Syllables.**

The intensity difference between the first syllable “rain” (considered to be stressed) and the second syllable “bow” (considered to be unstressed) changed slightly from the earlier portion of the passage to the later portion (Figure 7). Negative values in Figure 7 represent a decrease in intensity from the first “rain” in the passage for each participant. Results of the repeated-measures ANOVA for intensity differences within syllables (that is, the intensity difference between the first occurrence of “rain” and the first occurrence of “bow”, compared to the intensity difference between the second occurrence of “rain” and the second occurrence of
“bow”) revealed no main effect of segment, $F(1,10)=0.791; p=0.395; \eta^2=0.073$, and no effect of Sex, $F(1,10)=0.047; p=0.832; \eta^2=0.005$. The Segment by Sex interaction effect was not significant, $F(1,10)=0.000; p=0.986; \eta^2=0.000$. This finding that the intensity difference between “rain” and “bow” for its first occurrence was not statistically different from the intensity difference between “rain” and “bow” later in the reading supports the hypothesis of maintaining a clear speech cue. A fade of the clear speech cue would most likely have narrowed the difference in intensity between “rain” and “bow”.

![Intensity Differences from First "Rain" Stressed Syllable by Participant](image)

**Figure 7. Intensity Differences from First “Rain” Stressed Syllable by Participant.** The first “rain” was used as a referent point (a value of zero) in this figure. All other values were subtracted from the value of the word “rain” for each participant. The change in intensity varies by participant.

**Difference in Intensity from Beginning of Passage to End of Passage.**

According to the results of a one sample $t$-test, there was a significant decrease in the intensity from the first instance to the last instance of the word “rain” $t(11)=2.625, p=0.004$, and the first instance and last instance of the word “bow” $t(11)=6.886, p<.001$. The mean decrease in
the intensity of “rain” was 3.68 dB (SD=3.51), and the mean decrease in the intensity of “bow” was 4.6 dB (SD=2.32). Eleven of the 12 “rain” comparisons were lower in intensity for the later production, and all 12 “bow” comparisons were lower (Figure 7). These results do not support the hypothesis that there would be no change in intensity across the reading if the clear speech cue were maintained.
DISCUSSION

Speech and Articulation Rates

Speech rate (syllables per second with pauses included, Figure 1) increased over time in all segments except for the fourth segment. The speech rate was most likely reduced in segment 4 because of the increase in number of natural pauses, due to punctuation (instead of 1 or 2 for the other segments). This is supported by the more consistent trend of rate for the articulation rate, where pauses were removed (Figure 2). The increase in speech and articulation rates suggests that the participants countered the expectation of maintaining the effect of the clear speech request. That is, participants did not continue producing a relatively slower rate for better precision throughout the passage. The linear trend also demonstrates that the cue to “speak clearly” was lost almost immediately after beginning to speak. The average articulation rate of 4.62 syl/s in Goberman (2005) is similar to the 4.68 syl/s for the end of the passage in the current study. Similarly, Skodda & Schlegel (2008) noted that adults with PD demonstrated an increase in speech rate, possibly attributed to impaired motor planning. While the increase in rate could be attributed to anticipation for the end of the passage, Skodda & Schlegel (2008) noted that in adults with PD this trend was exaggerated.

Percent Pause Time

There was a tendency for the percent pause time to correspond to the number of natural pauses within each segment in the reading of the Rainbow Passage. Figure 8 suggests this trend. That is, the percent pause time tends to increase as the number of potential natural speaking pauses increase, from only one for segments 2 and 3 to three for segment 4.
Figure 8. Number of Natural Pauses Within a Segment in Relation to Percent Pause Time. The segments corresponding to 1, 2, or 3 natural pauses are given by the symbols.

Intensity Difference

The intensity difference between stressed and unstressed syllables for the word “rainbow” was not significantly different between the beginning of the passage and the end of the passage (Figure 7). The lack of significant change in intensity difference was consistent with maintaining the clear speech cue (or perhaps consistent with not having any clear speech effect). However, the difference in intensity between the beginning of the passage and the end of the passage as evidenced by the change in intensity levels for the syllables rain and bow, did not support the maintenance of the clear speech cue. By providing the cue “speak as if I’m having trouble hearing you”, an increase in intensity was expected as a distinguishing characteristic of the clearer speech; while the increase was observed, the increase did not last past the first half of the passage.

Fundamental Frequency

The overall fundamental frequency decreased from the beginning of the passage to the end (Figure 4). The average difference of approximately 1 ST from beginning to end would
most likely be difficult to hear perceptually when listening to the entire passage. This small change in mean $F_o$, even though statistically significant, may support the maintenance of the clear speech cue. However, the strong trend to decrease the standard deviation of $F_o$ (Figure 6) counters maintaining the clear speech behavior. When examining the variance in $F_o$ over time, the variance in $F_o$ decreased from the beginning of the passage to the end.
CONCLUSIONS

The present study found that the clear speech request or cue to “produce the items as clearly as possible, as if I am having trouble hearing or understanding you” did not provide lasting effects on speech rate, articulation rate, $F_o$ standard deviation, or intensity throughout the Rainbow Passage reading task. The clear speech cue faded almost immediately relative to speech and articulation rates and $F_o$ standard deviation, seen as changes between segments 1 and 2. The measures that may appear to support the maintenance of the clear speech cue, mean $F_o$ and intensity difference between the two syllables of “rainbow”, may suggest that production of some prosodic features (laryngeal, short-term respiratory) may be more resistant to change, whereas more global aspects of speech (long-term articulatory, long-term respiratory) are less resistant to change away from the clear speech attempt.

Clinically, the findings of this study may suggest that the use of general verbal cues (like the clear speech cue in this study) in the treatment of characteristics of Parkinsonian speech may not be highly effective. Clinicians should therefore be cautious when using verbal cues with adults with PD, particularly when attempting to adjust laryngeal behaviors or short-term respiratory behaviors. Clinicians may attempt to employ a training program to increase the lasting effects of a verbal cue, or possibly use continued repetitions of a verbal cue. Further research regarding the specificity of a cue, effective training programs associated with verbal cues, or the efficiency of visual or tactile cues on characteristics of Parkinsonian speech, is necessary to determine the most effective treatment techniques to help adults with Idiopathic Parkinson Disease.
REFERENCES


Speech Rate

Figure A.1. Speech Rate for Participant PD01. The speech rate for this participant per segment number in syl/s.

Figure A.2. Speech Rate for Participant PD02. The speech rate for this participant per segment number in syl/s.
Figure A.3. Speech Rate for Participant PD03. The speech rate for this participant per segment number in syl/s.

Figure A.4. Speech Rate for Participant PD04. The speech rate for this participant per segment number in syl/s.
Figure A.5. Speech Rate for Participant PD05. The speech rate for this participant per segment number in syl/s.

Figure A.6. Speech Rate for Participant PD06. The speech rate for this participant per segment number in syl/s.
Figure A.7. Speech Rate for Participant PD07. The speech rate for this participant per segment number in syl/s.

Figure A.8. Speech Rate for Participant PD08. The speech rate for this participant per segment number in syl/s.
Figure A.9. Speech Rate for Participant PD09. The speech rate for this participant per segment number in syl/s.

Figure A.10. Speech Rate for Participant PD10. The speech rate for this participant per segment number in syl/s.
Figure A.11. Speech Rate for Participant PD11. The speech rate for this participant per segment number in syl/s.

Figure A.12. Speech Rate for Participant PD12. The speech rate for this participant per segment number in syl/s.
APPENDIX B

Articulation Rate

Articulation Rate PD01

Figure B.1. Articulation Rate for Participant PD01. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.

Articulation Rate PD02

Figure B.2. Articulation Rate for Participant PD02. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.
Figure B.3. Articulation Rate for Participant PD03. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.

Figure B.4. Articulation Rate for Participant PD04. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.
Figure B.5. Articulation Rate for Participant PD05. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.

Figure B.6. Articulation Rate for Participant PD06. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.
Figure B.7. Articulation Rate for Participant PD07. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.

Figure B.8. Articulation Rate for Participant PD08. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.
Figure B.9. Articulation Rate for Participant PD09. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.

Figure B.10. Articulation Rate for Participant PD10. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.
Figure B.11. Articulation Rate for Participant PD11. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.

Figure B.12. Articulation Rate for Participant PD12. The articulation rate for this participant per segment number in syl/s, articulation rate is rate of speech following the removal of pauses.
APPENDIX C

Percent Pause Time

Figure C.1. Percent Pause Time for Participant PD01. The percentage of time the reader paused during each segment. Calculated using: \(100 \times \left(\frac{\text{total time} - \text{articulation time}}{\text{total time}}\right)\).

\[
y = -0.76x + 12.24 \\
R^2 = 0.02421
\]

Figure C.2. Percent Pause Time for Participant PD02. The percentage of time the reader paused during each segment. Calculated using: \(100 \times \left(\frac{\text{total time} - \text{articulation time}}{\text{total time}}\right)\).

\[
y = 1.044x + 9.586 \\
R^2 = 0.27131
\]
Figure C.3. Percent Pause Time for Participant PD03. The percentage of time the reader paused during each segment. Calculated using: 100 x [(total time – articulation time)/total time].

Figure C.4. Percent Pause Time for Participant PD04. The percentage of time the reader paused during each segment. Calculated using: 100 x [(total time – articulation time)/total time].
Figure C.5. Percent Pause Time for Participant PD05. The percentage of time the reader paused during each segment. Calculated using: 100 x [(total time – articulation time)/total time].

Figure C.6. Percent Pause Time for Participant PD06. The percentage of time the reader paused during each segment. Calculated using: 100 x [(total time – articulation time)/total time].
Figure C.7. Percent Pause Time for Participant PD07. The percentage of time the reader paused during each segment. Calculated using: $100 \times \left[ \frac{\text{total time} - \text{articulation time}}{\text{total time}} \right]$.

Figure C.8. Percent Pause Time for Participant PD08. The percentage of time the reader paused during each segment. Calculated using: $100 \times \left[ \frac{\text{total time} - \text{articulation time}}{\text{total time}} \right]$.
Figure C.9. Percent Pause Time for Participant PD09. The percentage of time the reader paused during each segment. Calculated using: \(100 \times \frac{\text{total time} - \text{articulation time}}{\text{total time}}\).

Figure C.10. Percent Pause Time for Participant PD10. The percentage of time the reader paused during each segment. Calculated using: \(100 \times \frac{\text{total time} - \text{articulation time}}{\text{total time}}\).
Figure C.11. Percent Pause Time for Participant PD11. The percentage of time the reader paused during each segment. Calculated using: 100 x \[\frac{(\text{total time} - \text{articulation time})}{\text{total time}}\].

Figure C.12. Percent Pause Time for Participant PD12. The percentage of time the reader paused during each segment. Calculated using: 100 x \[\frac{(\text{total time} - \text{articulation time})}{\text{total time}}\].
APPENDIX D

Fundamental Frequency

<table>
<thead>
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<th>Participant - Sex</th>
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<th>Beginning</th>
<th>End</th>
</tr>
</thead>
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<td></td>
<td>Hz</td>
<td>Semi-tones</td>
<td>Hz</td>
<td>Semi-tones</td>
</tr>
<tr>
<td>PD03 - M</td>
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<td>14.26</td>
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<td>PD04 - M</td>
<td>131.97</td>
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<tr>
<td>PD11 - M</td>
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<td>127.93</td>
<td>10.4</td>
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<tr>
<td>PD12 - M</td>
<td>106.78</td>
<td>8.49</td>
<td>101.94</td>
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<td>PD01 - F</td>
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</tr>
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<td>PD02 - F</td>
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<td>20.73</td>
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<td>20.37</td>
</tr>
<tr>
<td>PD05 - F</td>
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<td>17.99</td>
<td>186.36</td>
<td>18.13</td>
</tr>
<tr>
<td>PD06 - F</td>
<td>161.33</td>
<td>15.63</td>
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<tr>
<td>PD08 - F</td>
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<td>20.51</td>
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<tr>
<td>PD10 - F</td>
<td>191.36</td>
<td>18.58</td>
<td>177.83</td>
<td>17.32</td>
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</table>

Table D.1. Composite Fundamental Frequency Data. Fundamental frequency data per participant in both Hz and Semitones.

![Fundamental Frequency Over Time PD01](image)

**Figure D.1. Fundamental Frequency Over Time for Participant PD01.** Each frequency represented within the pitch listening throughout the reading of the entire passage.
**Figure D.2. Fundamental Frequency Over Time for Participant PD02.** Each frequency represented within the pitch listening throughout the reading of the entire passage.

**Figure D.3. Fundamental Frequency Over Time for Participant PD03.** Each frequency represented within the pitch listening throughout the reading of the entire passage.
Figure D.4. Fundamental Frequency Over Time for Participant PD04. Each frequency represented within the pitch listening throughout the reading of the entire passage.

Figure D.5. Fundamental Frequency Over Time for Participant PD05. Each frequency represented within the pitch listening throughout the reading of the entire passage.
**Figure D.6. Fundamental Frequency Over Time for Participant PD06.** Each frequency represented within the pitch listening throughout the reading of the entire passage.

**Figure D.7. Fundamental Frequency Over Time for Participant PD07.** Each frequency represented within the pitch listening throughout the reading of the entire passage.
Figure D.8. Fundamental Frequency Over Time for Participant PD08. Each frequency represented within the pitch listening throughout the reading of the entire passage.

Figure D.9. Fundamental Frequency Over Time for Participant PD09. Each frequency represented within the pitch listening throughout the reading of the entire passage.
Figure D.10. Fundamental Frequency Over Time for Participant PD10. Each frequency represented within the pitch listening throughout the reading of the entire passage.

Figure D.11. Fundamental Frequency Over Time for Participant PD11. Each frequency represented within the pitch listening throughout the reading of the entire passage.
Figure D.12. Fundamental Frequency Over Time for Participant PD12. Each frequency represented within the pitch listening throughout the reading of the entire passage.

Fundamental Frequency Average Per Segment

Figure D.13. Average Fundamental Frequency of Each Segment for Participant PD01. The average fundamental frequency per segment for this participant.
Figure D.14. Average Fundamental Frequency of Each Segment for Participant PD02. The average fundamental frequency per segment for this participant.

Figure D.15. Average Fundamental Frequency of Each Segment for Participant PD03. The average fundamental frequency per segment for this participant.
Figure D.16. Average Fundamental Frequency of Each Segment for Participant PD04. The average fundamental frequency per segment for this participant.

Figure D.17. Average Fundamental Frequency of Each Segment for Participant PD05. The average fundamental frequency per segment for this participant.
Figure D.18. Average Fundamental Frequency of Each Segment for Participant PD06. The average fundamental frequency per segment for this participant.

Figure D.19. Average Fundamental Frequency of Each Segment for Participant PD07. The average fundamental frequency per segment for this participant.
Figure D.20. Average Fundamental Frequency of Each Segment for Participant PD08. The average fundamental frequency per segment for this participant.

Figure D.21. Average Fundamental Frequency of Each Segment for Participant PD09. The average fundamental frequency per segment for this participant.
Figure D.22. Average Fundamental Frequency of Each Segment for Participant PD10. The average fundamental frequency per segment for this participant.

Figure D.23. Average Fundamental Frequency of Each Segment for Participant PD11. The average fundamental frequency per segment for this participant.
Figure D.24. Average Fundamental Frequency of Each Segment for Participant PD12. The average fundamental frequency per segment for this participant.
APPENDIX E

Intensity

<table>
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<th>Participant Number</th>
<th>Beginning of Passage</th>
<th>End of Passage</th>
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<td></td>
<td>Intensity First Rain</td>
<td>Intensity First Bow</td>
</tr>
<tr>
<td>1</td>
<td>60.13</td>
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<tr>
<td>2</td>
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<td>12</td>
<td>78.98</td>
<td>71.05</td>
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</table>

Table E.1. Raw Intensity Data for “Rainbow”. The intensity of the first and last instance of the word “Rainbow” separated by syllable (stressed or unstressed).

![Intensity Variation Between Stressed and Unstressed Syllables](image)

Figure E.2. The Intensity Variation for Stressed and Unstressed Syllables. The representation of intensity in dB for the first and last instances of the word “rainbow” within the passage.