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# Acoustic and Perceptual Consequences of Clear and Loud Speech

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## Abstract

**Objective—**Several issues concerning F2 slope in dysarthria were addressed by obtaining speech acoustic measures and judgments of intelligibility for sentences produced in Habitual, Clear and Loud conditions by speakers with Parkinson's disease (PD) and healthy controls.

**Patients and Methods—**Acoustic measures of average and maximum F2 slope for diphthongs, duration and intensity were obtained. Listeners judged intelligibility using a visual analog scale. Differences in measures among groups and conditions as well as relationships among measures were examined.

**Results—**Average and maximum F2 slope metrics were strongly correlated, but only average F2 slope consistently differed among groups and conditions, with shallower slopes for the PD group and steeper slopes for Clear speech versus Habitual and Loud. Clear and Loud speech were also characterized by lengthened durations, increased intensity and improved intelligibility versus Habitual. F2 slope and intensity were unrelated, and F2 slope was a significant predictor of intelligibility.

**Conclusion—**Average diphthong F2 slope was more sensitive than maximum F2 slope to articulatory mechanism involvement in mild dysarthria in PD. F2 slope holds promise as an objective measure of treatment-related changes in the articulatory mechanism for therapeutic techniques that focus on articulation.

## Introduction

The slope of the second formant (F2) frequency is an acoustic measure reflecting rate of vocal tract shape change [1]. Shallower slopes also are associated with slower lingual movement speeds [2]. Compared to healthy talkers, reduced F2 slopes have been reported for a variety of dysarthrias and neurological diagnoses, including Parkinson's disease (PD) – the clinical population of interest to the current study [see reviews in 1-5]. Research further suggests that F2 slope measures do not differ for dysarthrias of different etiologies or types [4, 5]. Finally, F2 slope is sensitive to dysarthria severity such that speakers with more

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severe dysarthria or relatively poorer intelligibility have shallower F2 slopes compared to speakers with less severe dysarthria or relatively better intelligibility [2, 4, 5].

Although F2 slope in dysarthria has been studied a fair amount, several issues deserve additional attention. One of these issues is the utility of average F2 slope metrics, as reported in the studies reviewed in the preceding paragraph, versus extreme F2 slope metrics for characterizing articulatory behavior in dysarthria. By way of background, F2 slope is typically quantified as transition extent (TE) divided by transition duration (TD), with transition onset and offset identified using the 20 Hz/20 ms rule [6]. The traditional slope measure thus reflects overall or average rate of spectral change during the operationally-defined transition interval. F2 slope also may be computed on a point by point basis from a linear predictive coding (LPC) - generated F2 trajectory to yield a time history of instantaneous slope values. The transition interval is still identified using the 20 Hz/20 ms rule and instantaneous slope values are averaged over the transition interval to provide an overall or average F2 slope metric which correlates strongly with the traditional TE/TD measure [2, 7]. This approach also allows extreme instantaneous slope values, such as maxima, to be identified. A recent study of Multiple Sclerosis (MS) further concluded that extreme F2 slope measures were more sensitive to mild dysarthria than average slope measures [8]. Only one dysarthria study has reported extreme F2 slope metrics, however, and additional studies obviously are needed before drawing strong conclusions regarding the utility of extreme F2 slope metrics in mild dysarthria. Indeed, there is likely some redundancy between average and extreme slope measures owing to their part-whole relationship, although the relationship has not been empirically evaluated.

F2 slope also shows strong potential as an objective measure of treatment-related changes in the articulatory mechanism for individuals with PD [1], yet few treatment-related studies of PD have reported F2 slope measures. Moreover, results of these studies which have employed formal training programs such as the Lee Silverman Voice Treatment® (LSVT) as well as stimulation are equivocal [9, 10]. An increased vocal intensity is probably the most widely used treatment technique for PD, but clear speech is another global therapy technique that shows promise for addressing the speech impairment in PD as well as for enhancing intelligibility [11]. Global techniques span the time domain of an utterance and have the potential to simultaneously impact multiple speech subsystems [11]. In this manner, although an increased vocal intensity focuses on modifying respiratory-phonatory behavior, adjustments in segmental articulatory-behavior may occur. Similarly, clear speech focuses on exaggerated articulation, but respiratory-phonatory adjustments may also accompany clear speech. Comparative studies are critical for determining the relative advantages of therapeutic techniques, but studies comparing an increased intensity and clear speech in PD are lacking.

In conclusion, the present study sought to address several issues concerning F2 slope in dysarthria. First, the utility of an extreme or maximum F2 slope measure for characterizing articulatory behavior in dysarthria above and beyond the traditional, average or overall F2 slope measure is not well understood. The sensitivity of F2 slope to articulatory changes elicited by different global dysarthria therapy techniques also is not well-established. The current study sought to advance understanding of these issues by comparing the impact of clear speech and an increased vocal intensity on average and maximum F2 slope metrics for diphthongs produced by speakers with mild dysarthria secondary to PD as well as healthy controls. The strength of the relationship between average and maximum F2 slope metrics was quantified as was the relationship between F2 slope and vocal intensity. Our interest in the relationship between F2 slope and vocal intensity was motivated by statements in the dysarthria literature concerning the potential "spreading effect" of an increased vocal effort to the articulatory mechanism [12, 13], although studies of neurologically normal speech have demonstrated the reverse - that articulatory adjustments impact phonatory behavior [e.g., 14, 15]. Given the potential for clear speech and an increased intensity to enhance intelligibility as well as long-standing interest in the relationship between F2 slope and intelligibility in dysarthria, we also investigated the predictive relationship of F2 slope to intelligibility for the PD group. Magnitude production was used to elicit an increased vocal intensity and clear speech. Although results are not directly comparablye to studies employing training, studies investigating experimental manipulation of speech suggest the potential of intervention techniques [11, 16]. Finally, although speakers with PD in the current study had mild dysarthria, even persons with mild dysarthria may benefit from treatment focused on an increased vocal intensity or clear speech [11, 16].

# Method

## Speakers

Thirteen speakers with idiopathic Parkinson's disease (PD) and 15 healthy controls who are part of a larger project were included for study [17]. The PD group was comprised of seven men and six women 48 to78 years of age (Mean=68; SD=10), and the Control group was comprised of eight men and seven women 46 to 75 years of age (Mean = 61; SD=10). Participants were native speakers of American English, spoke with the Inland North dialect of western New York state and scored at least 26/30 on the Standardized Mini-Mental State [18]. No speaker used a hearing aid or had undergone neurosurgery. Two females with PD had completed LSVT more than two years prior to the study and one of these speakers was enrolled in a group, bi-monthly LSVT refresher course. Speakers with PD were recorded one hour prior to taking medication. All speakers were paid $10 per hour.

Table 1 describes the PD group. Sentence intelligibility scores for 10 student listeners as well as three speech-language pathologists' mean judgment of speech severity for the Grandfather Passage were previously reported [17]. The operationally-defined perceptual construct of speech severity aims to tap into prosodic adequacy and naturalness with values closer to 1.0 indicating more impairment and values closer to 0 indicating less impairment. Sentence intelligibility test (SIT) scores [19] in Table 1 for the PD group (M=89%; SD=3%) coupled with mid-range judgments of speech severity (M=.54; SD=.21) are consistent with clinical descriptions of mild dysarthria [16]. For comparison, the mean SIT score for the Control group was 93% (SD=2%), and mean speech severity was .26 (SD= .14). The slightly reduced intelligibility and elevated speech severity scores for controls likely reflects the fact that speech samples were pooled across normal and disordered speakers for these analyses [17]. Speakers with PD were further noted to have reduced segmental precision and a breathy, monotonous voice.

## Experimental Speech Stimuli and Procedures

Speakers were audio recorded in a sound treated room reading 25 Harvard Psychoacoustic Sentences [20] in a variety of conditions. The Habitual, Clear and Loud conditions were of interest to the current study. Across 12 sentences, there were 10 occurrences of /ɑɪ/ and four occurrences of /ɔɪ/ in stressed syllables of content words varying in sentence position and phonetic context. The acoustic signal was transduced using an AKG C410 head mounted microphone positioned 10 cm and 45 to 50 degrees from the left oral angle. The signal was preamplified, low pass-filtered at 9.8 kHz and digitized to computer hard disk at a sampling rate of 22 kHz using TF32 [21]. A calibration tone also was recorded to allow for offline measurement of vocal intensity from the acoustic signal. For the Loud condition, participants were instructed to use a vocal intensity twice as loud as their typical speech. For the Clear condition, participants were instructed to say each sentence twice as clearly as their typical speech. Speakers were told to exaggerate the movements of their mouth and were instructed that this is how they might speak to someone in a noisy environment or to someone with a hearing loss. Speakers also were told that their speech might be slower and louder than usual. Instructions were modeled after those used in other clear speech studies [22]. For each speaker and condition, a unique ordering of sentences was recorded. Sentences were read first in the Habitual condition with the order of the remaining conditions randomized across speakers.

## Acoustic Analysis

Acoustic measures were obtained using TF32. Measures of sentence-level SPL and articulatory rate served to document that that the magnitude production paradigm elicited production differences among conditions. Diphthong durations, described in the following paragraph, further documented segment-level duration differences among conditions. Sentences first were segmented into runs using the combined waveform and wideband (300-400 Hz) spectrographic displays. A run was operationally defined as a stretch of speech bounded by silent periods between words of at least 200 ms. Run onsets and offsets were identified using conventional acoustic criteria. Articulatory rate, in syllables per second, was determined by tallying the number of syllables per run and dividing by run duration. Mean SPL for each run was obtained by using the Root-Mean-Squared (RMS) intensity trace of TF32. For each speaker and condition, SPL and rate measures were averaged across runs.

Diphthong onsets and offsets were identified and labeled from the combined waveform and wideband (300-400 Hz) spectrographic displays. Pitch-synchronous LPC tracks on a wideband (300 Hz-400 Hz bandwidth; 26 coefficients) spectrogram were generated and computer-generated tracking errors were manually corrected. Diphthong duration was calculated as the time between diphthong onset and offset. Instantaneous slope was computed for each point of the LPC F2 formant time history as the change in frequency (Hz) divided by the change in time (ms). Instantaneous slope values were subsequently used to identify the onset and offset of each major, rising F2 transition using operational criteria approximating the 20 Hz/ 20 ms rule [6]. Maximum F2 slope was identified as the maximum instantaneous slope value of the F2 transition. Average F2 slope was obtained by averaging all instantaneous slope values during the operationally defined transition. For each speaker, condition and diphthong, segment durations and F2 slope measures were averaged across tokens.

## Perceptual Task

Fifty listeners aged 18 to 30 years judged sentence intelligibility. Listeners were native speakers of standard American English, had at least a high school diploma, reported no history of speech, language, or hearing problems, passed a hearing screening at 20 dB HL for octave frequencies from 250 to 8000 Hz bilaterally and were unfamiliar with speech disorders. Listeners were paid $10 per hour.

For each speaker, a random selection of the same 10 Harvard sentences produced in all conditions was studied to allow the perceptual task to be completed in a single session. To prevent ceiling effects, sentences were presented in multi-talker babble, as is commonly done in the clear speech literature [20]. Sentences first were normalized for peak amplitude using Goldwave Version 5 [23], and then mixed with 20-person babble [24, 25] in Goldwave. A signal to noise ratio (SNR) of -3 dB was applied to each sentence, as pilot testing indicated that this SNR minimized both floor and ceiling effects. This SNR also has been used in other studies [26, 27]. Stimuli were presented to listeners at 75 dB SPL via headphones (SONY, MDR V300) in a double-walled audiometric booth.

Listeners judged intelligibility using a computerized, continuous 150 mm Visual Analog Scale [17]. Each sentence was judged without knowledge of the speaker's neurological diagnosis or identity. Written and verbal instructions directed listeners to judge how well sentences could be understood, with endpoints of the continuous scale labeled as “Understand everything” to “Cannot understand anything”. Sentences for all speakers from the larger database and all conditions were pooled and divided into 10 sets. Sets were constructed to ensure each set was comprised of one sentence produced by each talker in each condition and that all 25 Harvard sentences were represented in similar proportions. Five listeners judged each set. To determine intrajudge reliability, 10% of the sentences were presented twice. Pearson product correlations for intrajudge reliability ranged from .60 to .88 (Mean =.72; SD =.07) for the 50 listeners. Interjudge reliability was assessed using the Intraclass correlation coefficient (ICC). Mean ICCs ranged from .85 to .91 (Mean=.85; SD=.02) across the 10 sets and were significant ($p$<.001). Listener reliability is considered further in the discussion.

## Data Analyses

Descriptive and parametric statistics were employed. The variables of articulatory rate, SPL, average F2 Slope, maximum F2 Slope, and intelligibility were fit with a mixed linear model in this repeated measures design. The within subjects factor was Condition (Habitual, Clear, Loud) and the between-subjects factor was Group (PD, Control). Covariates included age and speaker sex. F2 slope analyses also included diphthong segment duration as a covariate, given studies reporting a relationship between speech duration and F2 slope [2]. Post hoc comparisons were made using a Bonferroni correction. Relationships among variables were examined using correlation and regression analyses.

# Results

## Speech Durations and Vocal Intensity

Table 2 reports descriptive statistics for SPL and duration. The Condition effect was significant for articulation rate [F (2, 52) =70.88, *p*<.0001] and SPL [F (2, 52) =157.36, *p*<.0001]. Post hoc testing within groups confirmed differences for all pairs of conditions (*p*<.003), with the exception of the PD group's Habitual-Loud contrast for articulation rate. The Group effect also was significant for articulation rate [F (1, 24) =9.39; *p*=.005] and mean SPL [F (1, 24) =10.76, *p*=.003]. The interaction of Group and Condition also was significant for SPL [F (2, 52) =6.49, *p*=.003]. Post hoc testing indicated that the interaction was due to the PD group having a reduced SPL compared to controls in both the Clear and Loud conditions, but not Habitual (p<.004). Segment duration results were identical to those for articulation rate. To summarize, both groups increased vocal intensity in the Clear and Loud conditions relative to Habitual, with the magnitude of the increase being greatest for the Loud condition. SPL for the PD group also was reduced compared to controls in both the Clear and Loud conditions. Both groups also typically lengthened speech durations for the Clear and Loud conditions, although speech durations for the PD group tended to be accelerated compared to controls.

## F2 Slope

Table 3 reports descriptive statistics for slope. Within groups and conditions, average and maximum slope metrics were significantly correlated for both diphthongs, with Pearson *r* coefficients ranging from .76 to .92 (2-tailed tests, *p*<.002). Pooling data across groups and conditions yielded Pearson *r* coefficients for /ɔɪ/ and /aɪ/ of .90 and .88, respectively. The Group effect was only significant for average slope metrics [/ɔɪ/: F (1, 25) =16.70, *p*<.001; /ɑɪ/: F (1, 25) =15.69, *p*<.001]. The Condition effect was significant for all slope metrics, with the exception of maximum slope for /ɔɪ/ [average /ɔɪ/: F (2, 51) =9.05, *p*=.0004; average /ɑɪ/: F (2, 51) =21.28, *p*<.0001; maximum /ɑɪ/ F (2, 51) =7.97, *p*=.001)]. Post hoc tests within each group indicated steeper slopes for Clear versus both the Habitual and Loud conditions (p<.05), although for each group there was one instance in which the Clear-Loud contrast was not significant. Given the strong correlation between the two slope metrics as well as the fact that average but not maximum F2 slope consistently distinguished among groups and conditions, correlation and regression analyses reported in the remainder of the paper were performed using average slope measures.

## Relationship between F2 Slope and SPL

Regression analysis was used to quantify the relationship between SPL and average F2 slope within and across conditions for each group and diphthong. Data for males and females was pooled as the variable representing speaker sex was not significant in the statistical analysis for SPL. Only the Control group's Clear regression for /ɔɪ/ as well as the Control group's across-condition regression for /ɔɪ/ were significant (p<.05). Functions accounted for 3% and 8% of the variance, respectively, with a steeper slope associated with lower SPL.

### Intelligibility and Acoustic Predictors of Intelligibility

Descriptive statistics for intelligibility are reported in Table 2. Values closer to “0” indicate better intelligibility. The Group effect was significant, with poorer overall intelligibility for speakers with PD [$F (1, 24) = 13.84$, $p < .001$]. The Condition effect also was significant [$F (2, 52) = 26.85$, $p < .0001$]. Post hoc tests further indicated better intelligibility in the Clear and Loud conditions for both groups versus Habitual ($p < .003$), but no difference for Clear and Loud.

The relationship of average F2 slope to intelligibility for the PD group was examined using hierarchical regression analysis. Additional predictor variables included articulation rate and vocal intensity. Speaker sex was not significant in the intelligibility analysis previously summarized. Thus, as in other studies, data for men and women were pooled [2]. F2 slope values were averaged across diphthongs thus yielding a composite F2 slope metric similar to composite metrics for articulation rate, SPL and intelligibility. The model including only F2 slope accounted for 14% of the variance in intelligibility [$F (1, 37) = 7.388$, $p = .01$]. Adding articulation rate and SPL accounted for an additional 5% and 6% of the variance, respectively, although these increases were not statistically significant. The final model including all three predictors accounted for 23% of the variance in intelligibility [$F (3, 35) = 4.675$; $p = .008$]. The sign of the standardized beta coefficients indicated that a steeper F2 slope, slower articulation rate and higher SPL were associated with better intelligibility. Finally, all variance inflation factors were less than 2.0, indicating the absence of serious multicollinearity among predictor variables.

## Discussion

Major findings may be summarized as follows. Average and maximum F2 slope metrics were strongly correlated, but only average slope measures distinguished the two speaker groups, with shallower slopes for the PD group. With one exception, there also were significant differences in F2 slope metrics among speaking conditions, with steeper slopes for the Clear condition versus the Habitual and Loud conditions. Clear and Loud speech were further characterized by lengthened durations, increased intensity and improved intelligibility versus Habitual. F2 slope and intensity were unrelated but F2 slope was a significant predictor of intelligibility. The remainder of the discussion considers these findings and their implications in more detail.

In addition to eliciting adjustments in segmental articulation, as inferred from F2 slope, it is worth reiterating at the outset that the magnitude production paradigm was successful in eliciting variations in vocal intensity, speech duration and intelligibility. The nature of changes in vocal intensity and speech duration were similar for the Clear and Loud conditions relative to Habitual, although the magnitude of the adjustments differed. The finding of similar magnitudes of improvement in intelligibility for the Clear and Loud conditions versus Habitual further suggests the feasibility of using either a clear speech style or an increased vocal intensity therapeutically to enhance intelligibility for speakers with mild dysarthria secondary to PD. Comparative studies employing training paradigms are needed to build upon these results to determine whether the short-term effects for experimental speech stimuli demonstrated here can be maintained in the long-term for functional speech tasks.

The sensitivity of F2 slope to articulatory changes elicited by different global dysarthria therapy techniques was one topic of interest. With the exception of maximum F2 slope for /ɔɪ/, the Clear condition generally yielded F2 slopes for the PD group that not only were significantly different from Habitual, but also more closely approximated Habitual slopes for neurologically normal talkers. Thus, results support the suggestion that F2 slope might serve as an objective metric of treatment-related changes in the articulatory mechanism in PD [1], at least for behavioral techniques such as clear speech which focus on articulatory behavior. The finding that F2 slope metrics in the Loud condition did not differ from Habitual is not entirely unexpected given other studies [9, 10]. However, it is important to note that an increased vocal intensity has been shown to be associated with other types of segmental articulatory adjustments. For example, an expanded vowel space area and enhanced spectral distinctiveness for stops as well as increased movement velocities and displacements may accompany an increased vocal intensity [e.g., 9, 10, 13, 26]. Thus, F2 slope may simply not be sensitive to intensity-related adjustments in articulatory behavior. The lack of a robust relationship between F2 slope and SPL supports this suggestion.

The nature of the relationship between maximum and average F2 slope metrics also was of interest as well as the ability of both metrics to distinguish speakers with mild dysarthria from healthy controls. Average but not maximum F2 slope metrics were significantly reduced for the PD group versus controls. Thus, results do not support the suggestion that measures of extreme F2 slope are more sensitive to mild dysarthria than average slope measures [8]. The correlation analysis further indicated a great deal of redundancy or overlap for the two slope measures. Given that extreme F2 slope metrics were not consistently sensitive to condition-related adjustments in segmental articulation, the strong correlation between the two slope metrics, and the fact that only average F2 slope distinguished the PD and control groups, the value of obtaining maximum F2 slope metrics in dysarthria seems questionable. Before drawing strong conclusions, however, studies with greater speaker numbers and more varied phonetic contexts are needed.

Finally, an ongoing goal of dysarthria research is to identify aspects of speech potentially related to intelligibility. In the present study, a composite metric of average F2 slope was a significant predictor of intelligibility for the PD group when data were pooled across conditions, with articulation rate and vocal intensity explaining an additional small amount of the variance in intelligibility. Thus, as suggested in other studies, F2 slope is linked to intelligibility even in mild dysarthria and holds promise as an index of functional communication skill [2, 5]. The final regression model indicated that steeper F2 slopes, slower articulation rates, and higher vocal intensities were associated with better intelligibility. A clinical implication is that therapeutic techniques that elicit an increase in F2 slope, reduced articulation rate and increased vocal intensity would likely also maximize intelligibility.

### Caveats

Several factors should be kept in mind when interpreting results. The importance of studying intelligibility in dysarthria in adverse listening conditions has been noted, and multi-talker babble is arguably an ecologically valid perceptual environment [11]. However, results may differ for speech in quiet. Listener reliability metrics further suggest the challenging nature of the intelligibility task. Although some reliability metrics may appear modest, our metrics compare well to other studies using scaling tasks to measure intelligibility in dysarthria [e.g., 28-30]. Moreover, when the intelligibility data were reanalyzed using only listeners with intrajudge reliability of r=.7 or better, results were identical to those for the larger pool of 50 listeners. Finally, although unlikely, it is possible that LSVT history for two of the PD speakers had some bearing on the results. The direction of the effect would be to magnify differences between the Loud condition and other conditions, however. Thus, if anything, acoustic and intelligibility changes associated with the Loud condition are overestimated in the current study.

### Conclusions

In conclusion, average diphthong F2 slope was more sensitive than maximum F2 slope for capturing articulatory involvement in mild dysarthria in PD. Future studies are needed to determine whether F2 slope metrics might be sensitive to disease presence in the articulatory mechanism in PD prior to any observable reduction in intelligibility. F2 slope also holds promise as an objective measure of treatment-related changes in the articulatory mechanism for therapeutic techniques that focus on eliciting changes in articulation. Studies employing kinematic, acoustic, and perceptual methods, such as that of Yunusova and colleagues [2], would aid in further understanding the nature of the speech movements responsible for changes in F2 slope and the impact on intelligibility.

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## References

1. Weismer G, Yunusova Y, Bunton K. Measures to evaluate the effects of DBS on speech production. J Neurolinguist. 2012; 25:74–94.
2. Yunusova Y, Green JR, Greenwood L, Wang J, Pattee GL, Zinman L. Tongue movements and their acoustic consequences in amyotrophic lateral sclerosis. Folia Phoniatr Logop. 2012; 64:94–102. [PubMed: 22555651]
3. Weismer, G.; Kim, Y. Classification and taxonomy of motor speech disorders: What are the issues. In: Maassen, B.; van Lieshout, PHHM., editors. Speech motor control: New developments in basic and applied research. Oxford University Press; UK: 2010. p. 229-241.
4. Kim YJ, Weismer G, Kent RD, Duffy JR. Statistical models of F2 slope in relation to severity of dysarthria. Folia Phoniatr Logop. 2009; 61:329–335. [PubMed: 19864914]
5. Kim YJ, Kent RD, Weismer G. An acoustic study of the relationships among neurologic disease, dysarthria type and severity of dysarthria. J Speech Lang Hear Res. 2011; 54:417–429. [PubMed: 20884780] Tjaden K, Wilding GE. Rate and loudness manipulations in dysarthria: Acoustic and perceptual findings. J Speech Lang Hear Res. 2004; 47:766–783. [PubMed: 15324285]

6. Weismer G, Kent RD, Hodge M, Martin R. The acoustic signature for intelligibility test words. Journal of the Acoustical Society of America. 1988; 84:1281–1291. [PubMed: 3198863]
7. Richards, E.; Tjaden, K.; Lam, J.; Wilding, G. Poster presented at the ASHA Convention. Philadelphia PA: 2010. Diphthong F2 trajectories in dysarthria: Clear, loud and slow speech..
8. Rosen KM, Goozée JV, Murdoch BE. Examining the effects of multiple sclerosis on speech production: Does phonetic structure matter? J Commun Disord 2008. 41:49–69.
9. Dromey C, Ramig LO, Johnson AB. Phonatory and articulatory changes associated with increased vocal intensity in parkinson disease: A case study. J Speech Hear Res. 1995; 38:751–764. [PubMed: 7474969]
10. Tjaden K, Wilding GE. Rate and loudness manipulations in dysarthria: Acoustic and perceptual findings. J Speech Lang Hear Res. 2004; 47:766–783. [PubMed: 15324285]
11. Yorkston KM, Hakel M, Beukelman DR, Fager S. Evidence for effectiveness of treatment of loudness, rate, or prosody in dysarthria: A systematic review. Journal of Medical Speech-Language Pathology. 2007; 15:xi–xxxvi.
12. Fox CM, Morrison CE, Ramig LO, Sapir S. Current perspectives on the Lee Silverman Voice Treatment (LSVT) for individuals with idiopathic Parkinson disease. Am J Speech-Lang Pathol. 2002; 11:111–123.
13. Sapir S, Spielman J, Ramig L, Story B, Fox C. Effects of intensive voice treatment (the Lee Silverman Voice Treatment [LSVT]) on vowel articulation in dysarthric individuals with idiopathic Parkinson's disease: Acoustic and perceptual findings. J Speech Lang Hear Res. 2007; 50:899–912. [PubMed: 17675595]
14. Cookman S, Verdolini K. Interrelation of mandibular laryngeal functions. J Voice. 1999; 13:11–24. [PubMed: 10223671]
15. Sapir S. The intrinsic pitch of vowels: Theoretical, physiological, and clinical considerations. J Voice. 1989; 3:44–51.
16. Yorkston, KM.; Beukelman, DR.; Strand, EA.; Hakel, M. Management of motor speech disorders in children and adults. PRO-ED; Austin, Texas: 2010.
17. Sussman JE, Tjaden K. Perceptual measures of speech from individuals with Parkinson's Disease and Multiple Sclerosis: Intelligibility and beyond. J Speech Lang Hear Res. 2012; 55:1208–1219. [PubMed: 22232396]
18. Molloy, D. Standardized Mini-Mental State Examination. New Grange Press; Troy, NY: 1999.
19. Yorkston, K.; Beukelman, D. Sentence Intelligibility Test for Windows. Tice Technologies; Lincoln: NE: 1996.
20. IEEE. IEEE recommended practice for speech quality measurements. Institute of Electrical and Electronic Engineers; New York: 1969.
21. Milenkovic, P. TF32 [Computer software]. University of Wisconsin-Madison; Madison, WI: 2005.
22. Smiljanić R, Bradlow AR. Speaking and hearing clearly: Talker and listener factors in speaking style changes. Lang Linguis Compass. 2009; 3:236–264.
23. Goldwave Inc.. Goldwave (Version 5) [Software]. 2010. Available from http://www.goldwave.com/release.php
24. Frank T, Craig CH. Comparison of the auditec and rintelmann recordings of the NU-6. J Speech Hear Disord. 1984; 49:267–271. [PubMed: 6748621]
25. Nilsson M, Soli S, Sullivan J. Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and in noise. J Acoust Soc Am. 1994; 95:1085–1099. [PubMed: 8132902]
26. Ferguson S, Kewley-Port D. Vowel intelligibility in clear and conversational speech for normal-hearing and hearing-impaired listeners. J Acoust Soc Am. 2002; 112:259–271. [PubMed: 12141351]
27. Maniwa K, Jongman A, Wade T. Perception of clear English fricatives by normal-hearing and simulated hearing-impaired listeners. J. Acoust. Soc. Am. 2008; 123:1114–1125. [PubMed: 18247912]
28. Neel AT. Effects of loud and amplified speech on sentence and word intelligibility in parkinson disease. J Speech Hear Res. 2009; 52:1021–1033.

29. Van Nuffelen G, De Bodt M, Wuyts F, Van de Heyning P. The effect of rate control on speech rate and intelligibility in dysarthria. Folia Phoniatrica Logopaedica. 2009; 61:69–75.
30. Yunusova Y, Weismer G, Kent RD, Rusche NM. Breath-group intelligibility in dysarthria: Characteristics and underlying correlates. J Speech Hear Res. 2005; 48:1294–1310.

**Table 1**

Characteristics for participants with Parkinson's disease.

| Subject Code | Sex | Age | Years Post Diagnosis | Sentence Intelligibility Score (%) | Scaled Speech Severity Grandfather Passage |
|---|---|---|---|---|---|
| PD 01 | F | 76 | 20 | 84 | 0.85 |
| PD 02 | F | 78 | 3 | 95 | 0.38 |
| PD 04 | F | 48 | 11 | 90 | 0.59 |
| PD 05 | F | 74 | 2 | 87 | 0.68 |
| PD 06 | F | 75 | 5 | 90 | 0.62 |
| PD 08 | F | 63 | 2 | 89 | 0.33 |
| PD 01 | M | 76 | 12 | 87 | 0.49 |
| PD 02 | M | 65 | 8 | 89 | 0.51 |
| PD 03 | M | 58 | 13 | 89 | 0.70 |
| PD 04 | M | 55 | 5 | 92 | 0.17 |
| PD 06 | M | 66 | 3 | 91 | 0.23 |
| PD 07 | M | 67 | 32 | 90 | 0.67 |
| PD 08 | M | 78 | 4 | 90 | 0.80 |
| Mean (SD) | | 68 (9) | 9 (8) | 89 (3) | 0.54 (0.21) |

## Table 2

Means and standard deviations for speech durations, vocal intensity and scaled sentence intelligibility are reported. Smaller numerical values for intelligibility (i.e., values closer to 0) indicate relatively better intelligibility. Standard deviations are reported in parentheses.

| Measure | Group | Habitual | Clear | Loud |
|---|---|---|---|---|
| Articulatory Rate (syllables/second) | Control | 3.7 (0.5) | 2.4 (0.4) | 3.3 (0.6) |
| | PD | 4.0 (0.6) | 3.1 (0.7) | 3.9 (0.7) |
| Sound Pressure Level (dB SPL) | Control | 74 (2.8) | 79 (4.4) | 85 (4.2) |
| | PD | 72 (2.4) | 75 (3.6) | 79 (3.0) |
| Diphthong Duration /ɑɪ/ (ms) | Control | 178 (69) | 273 (119) | 231 (92) |
| | PD | 165 (51) | 224 (99) | 188 (69) |
| Diphthong Duration /ɔɪ/ (ms) | Control | 190 (43) | 304 (80) | 253 (65) |
| | PD | 178 (53) | 249 (101) | 206 (52) |
| Intelligibility | Control | .32 (.07) | .23 (.06) | .22 (.09) |
| | PD | .50 (.13) | .38 (.15) | .35 (.12) |

## Table 3

Group means and standard deviations for F2 slope metrics (Hz/ms) are reported. Speaker sex is denoted in Group codes (F=females; M=males).

| Measure | Group | Habitual | Clear | Loud |
|---|---|---|---|---|
| Maximum F2 /ɑɪ/ | CF | 16.8 (3.7) | 17.3 (4.9) | 16.7 (3.2) |
| | PDF | 13.0 (2.6) | 14.3 (2.9) | 12.9 (3.1) |
| | CM | 10.7 (1.3) | 11.9 (1.3) | 11.1 (1.3) |
| | PDM | 9.8 (1.9) | 11.1 (1.9) | 10.0 (1.6) |
| Average F2 /ɑɪ/ | CF | 8.8 (1.2) | 8.5 (1.5) | 7.8 (.9) |
| | PDF | 6.6 (1.3) | 6.9 (1.0) | 6.7 (1.0) |
| | CM | 6.6 (.8) | 6.6 (.6) | 6.4 (.7) |
| | PDM | 5.6 (1.0) | 6.2 (.9) | 5.8 (1.2) |
| Maximum F2 /ɔɪ/ | CF | 23.4 (6.3) | 23.0 (5.0) | 22.8 (7.5) |
| | PDF | 15.8 (6.1) | 17.7 (5.9) | 15.2 (4.0) |
| | CM | 12.7 (2.0) | 14.7 (3.0) | 13.7 (2.5) |
| | PDM | 11.8 (2.5) | 12.9 (3.2) | 11.5 (2.3) |
| Maximum F2 /ɔɪ/ | CF | 10.3 (1.9) | 10.3 (2.0) | 9.6 (2.1) |
| | PDF | 7.5 (1.7) | 7.8 (2.4) | 7.7 (1.5) |
| | CM | 7.2 (1.1) | 7.3 (1.1) | 6.7 (1.0) |
| | PDM | 5.9 (1.0) | 6.6 (1.2) | 5.8 (1.0) |