2003

Spectral Measures and Perceptual Ratings of Hypokinetic Dysarthria

Christopher Dromey
Brigham Young University, dromey@byu.edu

Original Publication Citation
Dromey, C. (2003). Spectral measures and perceptual ratings of hypokinetic dysarthria. Journal of Medical Speech-Language Pathology, 11, 85-94.

Spectral measures and perceptual ratings of hypokinetic dysarthria

Christopher Dromey, Ph.D.

Brigham Young University

Contact Address:

Christopher Dromey, Ph.D.

Brigham Young University

Department of ASLP

133 TLRB

Provo, UT 84602

(801) 422-6461 – voice

(801) 422-0197 – fax

dromey@byu.edu

Abstract

Ten individuals with Parkinson disease (PD) and hypokinetic dysarthria were compared with age-matched neurologically normal (NN) speakers on acoustic measures from speaking and vowel phonation tasks as well as on perceptual ratings of connected speech. Listeners identified differences between the groups when asked to judge the severity of vocal and articulatory impairment during reading. Several conventional acoustic measures failed to differentiate speakers with PD from NN speakers. However, measures of the shape (statistical moments) of the long term average spectrum (LTAS) revealed statistically significant differences between the groups across vowel phonation, reading and monologue tasks. The ease of computation of these spectral moments makes them appealing in clinical research.

Introduction

Hypokinetic dysarthria associated with Parkinson disease (PD) is characterized by a weak breathy voice, monotone and monoloud speech, rate disturbances, and articulatory imprecision (Adams, 1996; Gentil & Pollak, 1995; Logemann & Fisher, 1981). In order to describe hypokinetic dysarthria acoustically, as well as document changes related to treatment, researchers have employed a variety of measures that are intended to correspond to the relevant perceptual characteristics. For example, sound pressure level (SPL), which correlates with the listener's perception of loudness, has been investigated in a number of studies (Fox & Ramig, 1997; Ramig, Countryman, O'Brien, Hoehn, & Thompson, 1996; Ramig, Countryman, Thompson, & Horii, 1995). The degree to which speech is monotone has been quantified with measures of fundamental frequency variability (Dromey, Ramig, & Johnson, 1995; Ramig et al., 1995), expressed as semitone standard deviation (STSD). Speech rate, and the relative durations of phrases and pauses have also been examined quantitatively (Caligiuri, 1989; Hammen & Yorkston, 1996; Ramig et al., 1995).

In some cases, there is a clear association between an objective measure and the perceptual characteristic it represents. Psychophysical scales of pitch and loudness perception reveal fairly predictable relationships between what listeners perceive and what an instrument can measure. However, when the *quality* of phonation and articulation is studied, the relationship between listeners' perceptions and quantitative acoustic measures becomes more complex. As Kreiman and Gerratt (2000) note, "the acoustic signal itself does not possess quality, it evokes it in the listener" (p. 73). Previous work has addressed the difficulty in relating perceptual and acoustic measures

(Kent, 1996). It is generally acknowledged that qualitative judgments of speech are multifactorial, in that they do not correlate highly with acoustic measures along a single dimension (Kreiman, Gerratt, & Berke, 1994; Kreiman, Gerratt, Kempster, Erman, & Berke, 1993). As a result, some investigators have employed complex signal processing algorithms to examine the differences between normal and disordered voices.

Since all speech sounds originate in the vocal tract, differences in quality must be related to differences in the configuration and movement of vocal tract structures. Motor equivalence in sound production, and the complexity of the acoustic interactions between the sound source and the resonant characteristics of the vocal tract, make it impossible to know with certainty how the radiated sound relates to the specifics of production. Clearly, there are limitations in the use of acoustic measures in capturing the essence of what the listener perceives to be wrong in dysarthric speech. Nevertheless, their use is appealing because they may allow a quantification of severity and the documentation of changes that may accompany treatment. The challenge has always been to determine which specific acoustic characteristic sheds the most light on the particular disorder under investigation.

The present study arose out of the observation that while a group of individuals with hypokinetic dysarthria sounded impaired when compared with age-matched neurologically normal (NN) speakers, the acoustic measures that were presumed to most clearly reflect the perceptual deficits failed to differentiate the two groups. Ten of the more perceptibly impaired speakers from a larger group of 25 individuals with PD in a previous study (Dromey & Adams, 2000) were compared with 10 NN speakers on the acoustic measures of sound pressure level and fundamental frequency variability. When these measures showed no significant differences, further acoustic analysis was undertaken to learn whether there might be more relevant parameters to reflect the features of hypokinetic dysarthria that were readily perceptible in these speakers. It has been shown previously that hypokinetic dysarthria can be highly variable in its acoustic manifestation (Metter & Hanson, 1986). Nevertheless, it was hoped that the application of a different kind of acoustic analysis might allow quantification of this form of dysarthria.

It was reasoned that some of the prominent qualitative deficits in hypokinetic dysarthria may be related to the spectrum of the voice. Previous work has documented the fact that the voice is often the first speech component affected by Parkinson disease (Critchley, 1981; Logemann, Fisher, Boshes, & Blonsky, 1978), and that the prevalence of voice disorders in this population is high (Gentil & Pollak, 1995). Phonation in the absence of articulation has long been used to evaluate laryngeal function, since it allows a rather basic evaluation vocal fold activity. However, it is difficult to argue that vowel prolongation is representative of typical human communication.

Kent and colleagues (Kent, Weismer, Kent, Vorperian, & Duffy, 1999) have noted that qualitative examination of disordered speech can sometimes lead to the application of existing quantitative analyses in new ways. The clearly perceptible differences between speakers with PD and NN speakers in the present data set led to this process in the current study. One analysis technique that allows an evaluation of the spectrum over entire words and sentences is the long term average spectrum (LTAS). By averaging across all speech sounds, the LTAS provides insights into the function of the voice in a context other than sustained vowel phonation. This approach has been used in the past to investigate the relationship between spectral characteristics and speech ‘clarity’ (Kiukaanniemi, Siponen, & Mattila, 1982), as well as to examine the speech of individuals with known laryngeal pathologies (Klingholtz, 1990). In the present study, the goal was to ascertain whether LTAS analysis could be used to evaluate the audible differences between speakers with PD and those who are neurologically normal.

One way to describe the characteristics of a spectrum is with statistical measures of the energy distribution. These *spectral moments* reflect the central tendency and shape of the spectrum. Recent articulatory acoustic studies of dysarthria have shown that the spectral distribution of noise energy in fricatives can be used to quantify articulatory deficits. One example is a reduction in the distinctiveness of alveolar and palatal fricatives (Tjaden & Turner, 1997). The goal of the present study was to determine whether the moments describing the shape of the LTAS during speech could differentiate between speakers with hypokinetic dysarthria and individuals of the same age without neurological disease.

Methods

Participants

Ten men with PD (ages 38 to 80, mean 66 years) and ten NN men (ages 36 to 82, mean 63 years) were included in the study. The individuals with PD were being treated pharmacologically at the Movement Disorders Clinic at the Toronto Western Hospital at the time of the study, and the diagnosis in each case was idiopathic Parkinson disease. The NN speakers were recruited from the local community as they responded to flyers or word of mouth invitations to participate. The ten men with PD were selected from the larger group because they were judged by the author to be the most dysarthric. The ten men selected from the NN group were those whose ages most closely matched the individuals with PD. All participants were part of a larger group previously studied in an investigation of loudness perception (Dromey & Adams, 2000).

Instrumentation

Participants sat in a sound treated booth and were recorded with a head-mounted microphone (AKG C-420) into a digital audio tape (DAT) recorder (Panasonic SV-3800). Sound pressure level was detected with a sound level meter (CEL 254), and the output of this device was also recorded with the DAT. Subsequently, both audio and sound level meter signals were re-digitized at 25 kHz using a commercial data acquisition system (Kay Elemetrics Computerized Speech Lab – CSL 4300B).

Tasks

The vowel /Ψ/ was produced at a comfortable pitch and loudness for approximately 3 seconds. Participants subsequently read the first 9 sentences of the Rainbow Passage (Fairbanks, 1960) and spoke a monologue for approximately 30 seconds on a topic of their choice.

Acoustic Data Analysis

Following digitization with CSL, the head-mounted microphone and sound level meter signals were analyzed to derive selected acoustic measures. For the vowels, a 2 second segment was extracted from the middle of the phonation and saved as a file for subsequent analyses. The measured variables included mean fundamental frequency (F_0), sound pressure level (SPL), jitter, shimmer, harmonics to noise ratio, and LTAS moments.

For connected speech, the entire 9 sentences of the reading passage (lasting approximately 50-60 seconds) and the entire monologue – both including pauses – were included in the analysis. Measures were made of mean F_0 and semitone standard deviation (STSD), mean SPL, and LTAS moments.

For LTAS analyses the window length was 8192 points, and the statistical moments were calculated automatically by CSL for the entire frequency range of 0 to 12.5 kHz.

Perceptual Rating

The first two sentences of the Rainbow Passage were selected from the digital recording for each speaker. These 20 original samples (along with 10 repeated samples to measure rater reliability) were randomized. The files were played back with a custom Matlab (2001) routine that allowed listeners to hear the samples as many times as they wished. The raters moved a visual analog slider on the computer display, and the software recorded their rating for each sample. The 5 raters were undergraduate students in speech-language pathology who had little experience with disordered speech. They received no training for this task. These listeners were asked to rate the reading sample for two features. One was a judgment of articulation, with the two ends of the scale labeled as “normal articulation” and “severely dysarthric.” The other judgment was of voice impairment, with the labels of “normal voice” at one end and “severely dysphonic” at the other. Both visual analog scales were otherwise unlabeled, with no numbers appearing on the screen. The software converted the position of the pointer to a number between 0 (normal) and 10 (severely dysarthric or dysphonic), which was stored in a text file.

Statistical Evaluation

Independent samples t-tests were run on the dependent variables to compare values for the PD and NN speaker groups. Given the number of tests, Tables 1-4 note the degree of Bonferroni adjustment that would be required for a conservative interpretation of the test statistics. Unadjusted *p*-values are reported in the tables to allow the reader to evaluate the results directly. Pearson correlations were calculated to evaluate the relationship between the perceptual ratings and the acoustic measures. Intraclass correlation coefficients were calculated to measure rater agreement.

Results

Reliability Measures

Each of the 5 raters who judged the speech samples had a mean correlation for the articulatory and voice ratings of greater than .75 (range .77 to .88) between the ratings of the original and the randomly repeated samples. The mean intraclass correlation coefficient, which measured the level of consistency between raters, was .786. Because the acoustic analyses were run as automated operations on previously saved files (2 seconds of vowel phonation, the entire reading passage and the 30 second monologue recording), re-measurement was not conducted because the analyses would have yielded identical results.

Acoustic Measures – Vowel Phonation

Means, standard deviations and t-test results for the vowel phonation task are presented in Table 1. SPL was higher for the NN speakers than for the individuals with PD, but the perturbation measures did not differ between them. In considering the two groups, the LTAS spectral mean and SD were lower and the skewness and kurtosis were higher for the speakers with PD. However, in spite of these group differences being significant at the .05 level, there was considerable variability between speakers. Figure 1 shows the individual LTA spectra for the speakers with PD, and Figure 2 shows spectra for the NN group. In both groups there are spectra with prominent harmonics across the display up to 2 kHz, as well as spectra with very few identifiable harmonic peaks.

Acoustic Measures – Connected Speech Tasks

Means and standard deviations for the acoustic measures in the reading and monologue tasks along with the t-test results are presented in Tables 2 and 3. Mean F_0 in the monologue task was higher for the PD group. For both reading and monologue tasks, the spectral moment measures from the LTAS analysis all significantly differed (at the .05 level) between groups. The spectral mean and standard deviation were lower for the speakers with PD, while their skewness and kurtosis were higher. Figures 3 and 4 show the mean LTAS shape for the PD and NN groups in the reading and monologue tasks respectively. These figures were generated by averaging the spectral values for each group and plotting the mean. The distribution for the PD group is more leptokurtic and skewed toward the lower frequencies, while the energy level for the higher frequencies remains lower than for the NN speakers.

Perceptual Ratings

Means, standard deviations and t-test results for the perceptual ratings of articulatory and vocal disorder severity are presented in Table 4. The severity of dysphonia, but not of articulation, for the speakers with PD was rated as being higher than for the NN speakers.

Correlations between perceptual and acoustic measures

No significant correlations were found between the perceptual ratings and the acoustic measures for the reading task (see Table 5). The ratings of articulatory and vocal severity were positively correlated ($r=.801$, $p<.001$).

Discussion

This study examined the acoustic differences between individuals with PD and age-matched NN speakers in vowel phonation and connected speech tasks. The goal was to determine whether statistical moments from the long term average spectrum (LTAS) would differentiate the groups better than the more commonly used measures of perturbation, noise to harmonics ratio, mean SPL, and STSD.

Vowel phonation SPL was reduced for the speakers with PD, which is consistent with previous findings (Fox & Ramig, 1997). Since louder phonation is typically associated with a less steep decay in the source spectrum (Gauffin & Sundberg, 1989), the SPL and spectral moment measures are consistent. However, this was only true in the present study for vowel phonation. Although SPL did not differ between groups for the speaking tasks, the spectral measures clearly differentiated them. Since the LTAS is influenced by all speech sounds, it is possible that differences in consonant articulation, as well as the glottal source, contribute to the spectral shape differences between the two groups.

It is worth noting that none of the measures of perturbation distinguished between the two groups at the .05 level in vowel phonation. This suggests that cycle-to-cycle measures of phonation may not be particularly relevant in this disorder. In contrast to the lack of differences in the perturbation measures, the LTAS moments differed significantly between the groups for vowel phonation. On an individual level, there was considerable variability in the vowel phonation spectra. Even though there were significant group differences in the spectral moments, individual speakers with PD had spectra that were similar to the NN group, and vice versa. Such inter-speaker variability in neurogenic communication disorders not unique to the present study (Metter & Hanson, 1986; Weismer, Jeng, Laures, Kent, & Kent, 2001).

In the speaking tasks, mean SPL and STSD did not differ between the PD and NN groups. Reduced loudness and monotone speech patterns have been identified as hallmarks of hypokinetic dysarthria (Adams, 1996; Gentil & Pollak, 1995), yet the acoustic correlates of these perceptual traits did not differ. Some previous accounts have reported differences in SPL between individuals with PD and those without neurological disease (Fox & Ramig, 1997; Illes, Metter, Hanson, & Iritani, 1988), although other studies have failed to find differences (Metter & Hanson, 1986). Mean F_0 in the monologue was higher for the speakers with PD than NN speakers, which is also consistent with other accounts (Illes et al., 1988; Metter & Hanson, 1986), and may be reflective of disease related stiffness in the vocal folds.

In contrast to the acoustic variables of SPL and F_0 variability, which had been intentionally selected to reflect the key perceptual variables of reduced loudness and monotone speech in hypokinetic dysarthria, the spectral moment variables discriminated more clearly between the PD and NN groups. The lower spectral mean and standard deviation, along with the elevated skewness and kurtosis measures for the speakers with PD suggest a weakness in the upper harmonics, with the main acoustic power in the voice being concentrated toward the lower frequencies. The NN speakers, on the other hand, had a broader distribution of energy across the spectrum, as reflected in the larger standard deviation and lower values for skewness and kurtosis.

The significant difference between groups on the perceptual rating of voice disorder severity indicates that there were perceptually relevant features that distinguished the two groups. However, differences in the articulatory ratings did not reach statistical significance. The finding that listeners identify phonatory function as being more impaired than articulatory accuracy is consistent with previous findings (Logemann & Fisher, 1981). These and other authors (Critchley, 1981) have reported a higher incidence of voice disorders than articulatory dysfunction in this population.

The lack of any statistically significant correlation between the acoustic and perceptual variables suggests that the individual acoustic measures do not correspond closely to the features that are most perceptually salient in judging vocal disorder severity. Ratings of dysphonia and the LTAS measures all differentiated the PD and neurologically normal groups. However, the lack of correlation between them indicates that they are not directly comparable. This absence of a clear relationship between acoustic and perceptual variables has been reported in previous studies (Kent, 1996; Parsa & Jamieson, 2001; Zwirner, Murry, & Woodson, 1993). A recent investigation, which compared spectral moment data with listener ratings of articulation, also found an unclear association between the two (Solomon, 2000).

The present study did not evaluate articulatory acoustic variables, which likely would have differed between the groups. Previous work has shown that compared to NN geriatrics, individuals with PD can have reduced vocalic segment durations and formant transitions (Forrest, Weismer, & Turner, 1989), although a recent study has shown that articulatory acoustic measures are not always substantially different in speakers with PD (Weismer et al., 2001).

The findings from the present study suggest that an analysis of the spectral characteristics of phonation, both in speaking and in isolated vowel production, more clearly distinguishes between individuals with hypokinetic dysarthria and NN speakers than do several more commonly used phonatory measures. Studies of articulatory acoustic variables would perhaps reveal more of the details that contribute to the differences between the two groups, but the labor-intensive nature of such analyses restricts their general applicability in large scale clinical contexts. In contrast, modern software tools, such as CSL, allow the user to quickly compute the LTAS and its statistical moments for an entire spoken passage. This ease of calculation of spectral moments from the LTAS could make them a useful overall index of dysarthria severity for clinical researchers who work with this population.

Acknowledgment

This research was supported by a grant from the James H. Cummings Foundation of Buffalo, New York. The author is grateful to Dr. Anthony Lang of the Movement Disorders Centre at the Toronto Western Hospital for his assistance in recruiting the participants with PD.

Reference List

Matlab (2001). (Version 6.1) [Computer software]. Natick, MA: The Mathworks.

Adams, S. G. (1996). Hypokinetic dysarthria in Parkinson's disease. In M.R.McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (pp. 259-282). New York: Thieme.

Caligiuri, M. P. (1989). The influence of speaking rate on articulatory hypokinesia in parkinsonian dysarthria. *Brain & Language, 36,* 493-502.

Critchley, E. M. (1981). Speech disorders of Parkinsonism: a review. *Journal of Neurology, Neurosurgery and Psychiatry, 44,* 751-758.

Dromey, C. & Adams, S. G. (2000). Loudness perception and hypophonia in Parkinson disease. *Journal of Medical Speech-Language Pathology, 8,* 255-259.

Dromey, C., Ramig, L. O., & Johnson, A. B. (1995). Phonatory and articulatory changes associated with increased vocal intensity in Parkinson disease: a case study. *Journal of Speech & Hearing Research, 38,* 751-764.

Fairbanks, G. (1960). *Voice and Articulation Drillbook.* (2nd ed.) New York: Harper & Row.

Forrest, K., Weismer, G., & Turner, G. S. (1989). Kinematic, acoustic, and perceptual analyses of connected speech produced by parkinsonian and normal geriatric adults. *Journal of the Acoustical Society of America, 85,* 2608-2622.

Fox, C. & Ramig, L. O. (1997). Vocal sound pressure level and self-perception of speech and voice in men and women with idiopathic Parkinson disease. *American Journal of Speech-Language Pathology, 6,* 85-94.

Gauffin, J. & Sundberg, J. (1989). Spectral correlates of glottal voice source waveform characteristics. *Journal of Speech & Hearing Research, 32,* 556-565.

Gentil, M. & Pollak, P. (1995). Some aspects of Parkinsonian dysarthria. *Journal of Medical Speech-Language Pathology, 3,* 221-237.

Hammen, V. L. & Yorkston, K. M. (1996). Speech and pause characteristics following speech rate reduction in hypokinetic dysarthria. *Journal of Communication Disorders, 29,* 429-444.

Illes, J., Metter, E. J., Hanson, W. R., & Iritani, S. (1988). Language production in Parkinson's disease: acoustic and linguistic considerations. *Brain & Language, 33,* 146-160.

Kent, R. D. (1996). Hearing and believing: Some limits to the auditory-perceptual assessment of speech and voice disorders. *American Journal of Speech-Language Pathology, 5,* 7-23.

Kent, R. D., Weismer, G., Kent, J. F., Vorperian, H. K., & Duffy, J. R. (1999). Acoustic studies of dysarthric speech: Methods, progress and potential. *Journal of Communication Disorders, 32,* 141-186.

Kiukaanniemi, H., Siponen, P., & Mattila, P. (1982). Individual differences in the long-term speech spectrum. *Folia Phoniatrica, 34,* 21-28.

Klingholtz, F. (1990). Acoustic recognition of voice disorders: A comparative study of running speech versus sustained vowels. *Journal of the Acoustical Society of America, 87,* 2218-2224.

Kreiman, J. & Gerratt, B. (2000). Measuring vocal quality. In R.D.Kent & M. J. Ball (Eds.), *Voice quality measurement* (pp. 73-101). San Diego: Singular Publishing Group.

Kreiman, J., Gerratt, B. R., & Berke, G. S. (1994). The multidimensional nature of pathologic vocal quality. *Journal of the Acoustical Society of America, 96,* 1291-1302.

Kreiman, J., Gerratt, B. R., Kempster, G. B., Erman, A., & Berke, G. S. (1993). Perceptual evaluation of voice quality: review, tutorial, and a framework for future research. *Journal of Speech & Hearing Research, 36,* 21-40.

Logemann, J. A. & Fisher, H. B. (1981). Vocal tract control in Parkinson's disease: phonetic feature analysis of misarticulations. *Journal of Speech & Hearing Disorders, 46,* 348-352.

Logemann, J. A., Fisher, H. B., Boshes, B., & Blonsky, E. R. (1978). Frequency and cooccurrence of vocal tract dysfunctions in the speech of a large sample of Parkinson patients. *Journal of Speech & Hearing Disorders, 43,* 47-57.

Metter, E. J. & Hanson, W. R. (1986). Clinical and acoustical variability in hypokinetic dysarthria. *Journal of Communication Disorders, 19,* 347-366.

Parsa, V. & Jamieson, D. G. (2001). Acoustic discrimination of pathological voice: sustained vowels versus continuous speech. *Journal of Speech, Language, & Hearing Research, 44,* 327-339.

Ramig, L. O., Countryman, S., O'Brien, C., Hoehn, M., & Thompson, L. (1996). Intensive speech treatment for patients with Parkinson's disease: short-and long-term comparison of two techniques. *Neurology, 47,* 1496-1504.

Ramig, L. O., Countryman, S., Thompson, L. L., & Horii, Y. (1995). Comparison of two forms of intensive speech treatment for Parkinson disease. *Journal of Speech & Hearing Research, 38,* 1232-1251.

Solomon, N. P. (2000). Changes in normal speech after fatiguing the tongue. *Journal of Speech, Language, & Hearing Research, 43,* 1416-1428.

Tjaden, K. & Turner, G. S. (1997). Spectral properties of fricatives in amyotrophic lateral sclerosis. *Journal of Speech, Language, & Hearing Research, 40,* 1358-1372.

Weismer, G., Jeng, J. Y., Laures, J. S., Kent, R. D., & Kent, J. F. (2001). Acoustic and intelligibility characteristics of sentence production in neurogenic speech disorders. *Folia Phoniatrica et Logopaedica, 53,* 1-18.

Zwirner, P., Murry, T., & Woodson, G. E. (1993). Perceptual-acoustic relationships in spasmodic dysphonia. *Journal of Voice, 7,* 165-171.

Table 1 Means, standard deviations, and t-test results on the acoustic variables comparing speakers with Parkinson disease (PD) and neurologically normal (NN) controls in the vowel phonation task.

	Mean		SD			
	PD	NN	PD	NN	*t*	*p*
Spectral mean (Hz)	203.7	372.9	73.0	161.0	3.028	.007
Spectral SD (Hz)	174.0	294.5	69.3	55.5	4.291	<.001
Skewness	16.4	4.5	10.6	3.1	3.379	.003
Kurtosis	733.3	86.2	770.9	75.7	2.654	.016
Mean F_0 (Hz)	141.8	120.9	30.2	14.4	1.985	.063
SPL (dB)	67.3	74.2	8.9	4.5	2.173	.043
Jitter (%)	2.39	1.48	1.21	1.04	1.792	.090
Shimmer (%)	3.23	3.50	1.52	1.28	0.431	.672
Noise to harmonic ratio	0.12	0.14	0.02	0.02	1.954	.066

To compensate for the large number of t-tests, a Bonferroni correction would result in an alpha level of .006 (.05 / 9) for the vowel data.

Table 2. Means, standard deviations, and t-test results on the acoustic variables comparing speakers with Parkinson disease (PD) and neurologically normal (NN) controls in the reading task.

	Mean		SD			
	PD	NN	PD	NN	*t*	*p*
Spectral mean (Hz)	198.6	283.2	35.1	74.8	3.237	.005
Spectral SD (Hz)	264.3	418.5	128.7	163.1	2.348	.031
Skewness	23.3	13.3	8.9	5.6	3.030	.007
Kurtosis	905.3	296.1	553.1	209.6	3.257	.004
Mean F_0 (Hz)	133.5	114.6	23.1	20.2	1.948	.067
Semitone SD	2.3	2.7	0.5	0.6	1.546	.139
SPL (dB)	64.7	65.9	4.9	3.3	0.661	.517

To compensate for the large number of t-tests, a Bonferroni correction would result in an alpha level of .007 (.05 / 7) for the reading data.

Table 3. Means, standard deviations, and t-test results on the acoustic variables comparing speakers with Parkinson disease (PD) and neurologically normal (NN) controls in the monologue task.

	Mean		SD			
	PD	NN	PD	NN	*t*	*p*
Spectral mean (Hz)	204.5	281.9	44.6	70.3	2.942	.009
Spectral SD (Hz)	312.3	482.4	159.0	181.8	2.226	.039
Skewness	22.0	12.4	9.3	4.6	2.915	.009
Kurtosis	837.8	266.6	673.6	236.8	2.530	.021
Mean F_0 (Hz)	136.2	114.4	23.2	19.4	2.287	.035
Semitone SD	2.4	2.7	0.5	0.6	1.226	.236
SPL (dB)	64.1	64.7	4.5	3.2	0.367	.718

To compensate for the large number of t-tests, a Bonferroni correction would result in an alpha level of .007 (.05 / 7) for the monologue data.

Table 4. Means, standard deviations, and t-test results on the acoustic variables comparing speakers with Parkinson disease (PD) and neurologically normal (NN) controls on the perceptual variables of articulatory and vocal disorder severity.

	Mean		SD			
	PD	NN	PD	NN	*t*	*p*
Articulatory severity	2.5	1.4	1.7	0.9	1.866	.078
Vocal severity	3.3	1.2	1.4	0.9	3.926	.001

A Bonferroni correction would result in an alpha level of .025 (.05 / 2) for the perceptual variable data.

Table 5. Correlation coefficients between perceptual judgments of articulation and voice disorder severity and acoustic variables for all speakers in the reading task.

	Severity judgment			
	Articulation		Voice	
	r	*p*	*r*	*p*
Voice severity	0.801	<.001		
F_0	0.359	.120	0.353	.127
STSD	-0.128	.592	-0.103	.667
SPL	0.238	.312	-0.022	.926
Spectral mean	-0.192	.418	-0.364	.115
Spectral SD	-0.240	.308	-0.336	.147
Skewness	0.027	.911	0.091	.702
Kurtosis	0.183	.441	0.176	.457

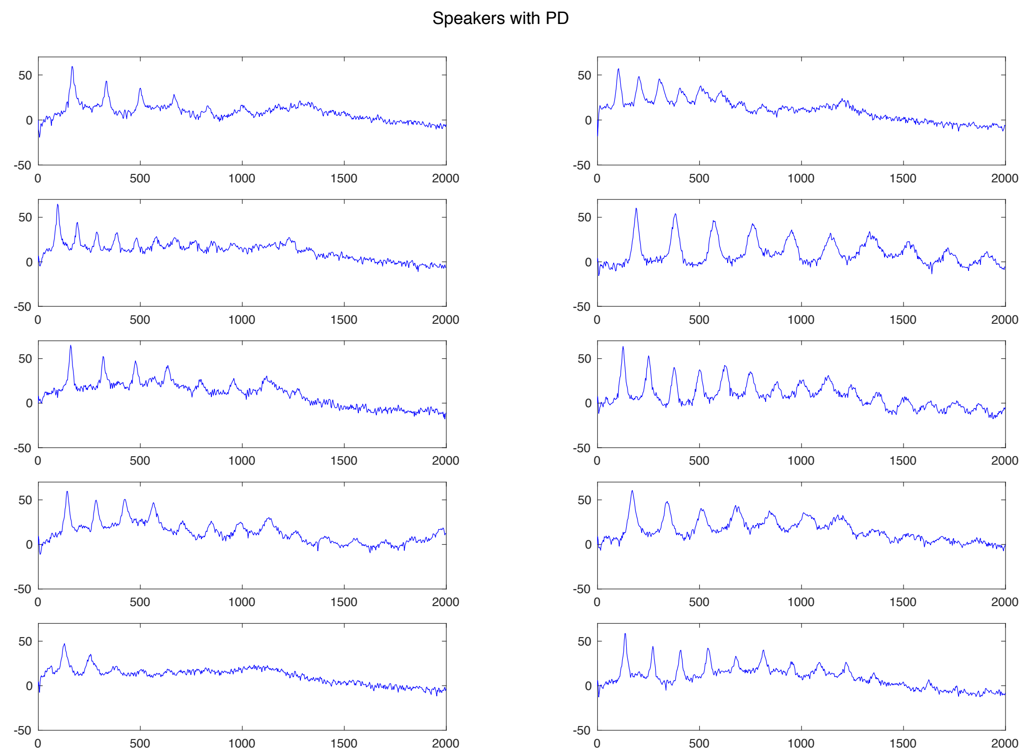
Figure Legend

Figure 1. Long term average spectrum traces for the 10 individual speakers with PD for vowel phonation.

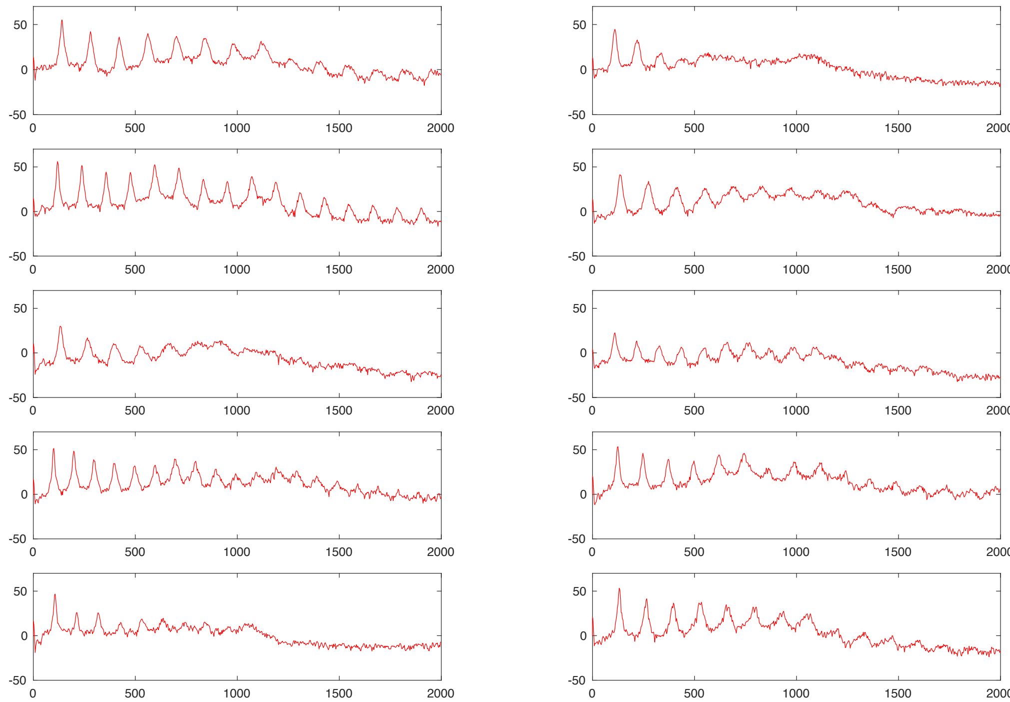
Figure 2. Long term average spectrum traces for the 10 neurologically normal speakers for vowel phonation.

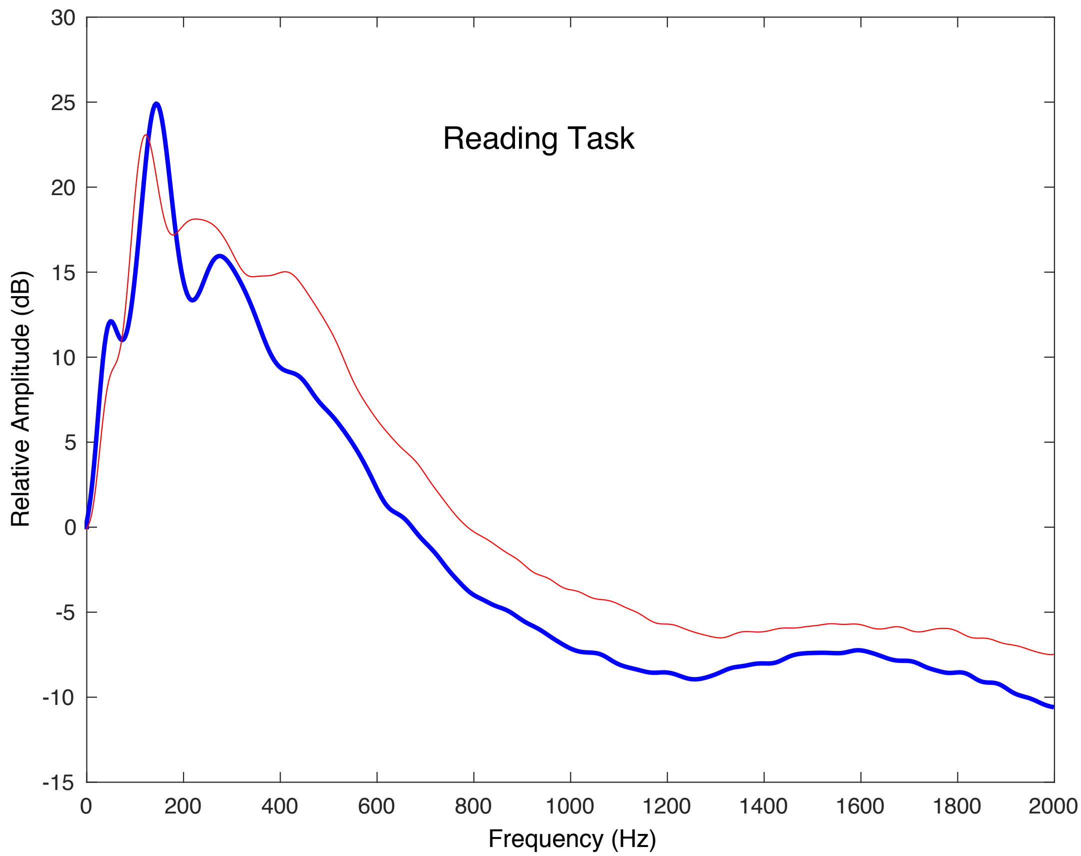
Figure 3. Long term average spectrum traces comparing PD and NN groups during the reading task. Plots represent the mean for each group of 10 speakers and have been smoothed for clarity.

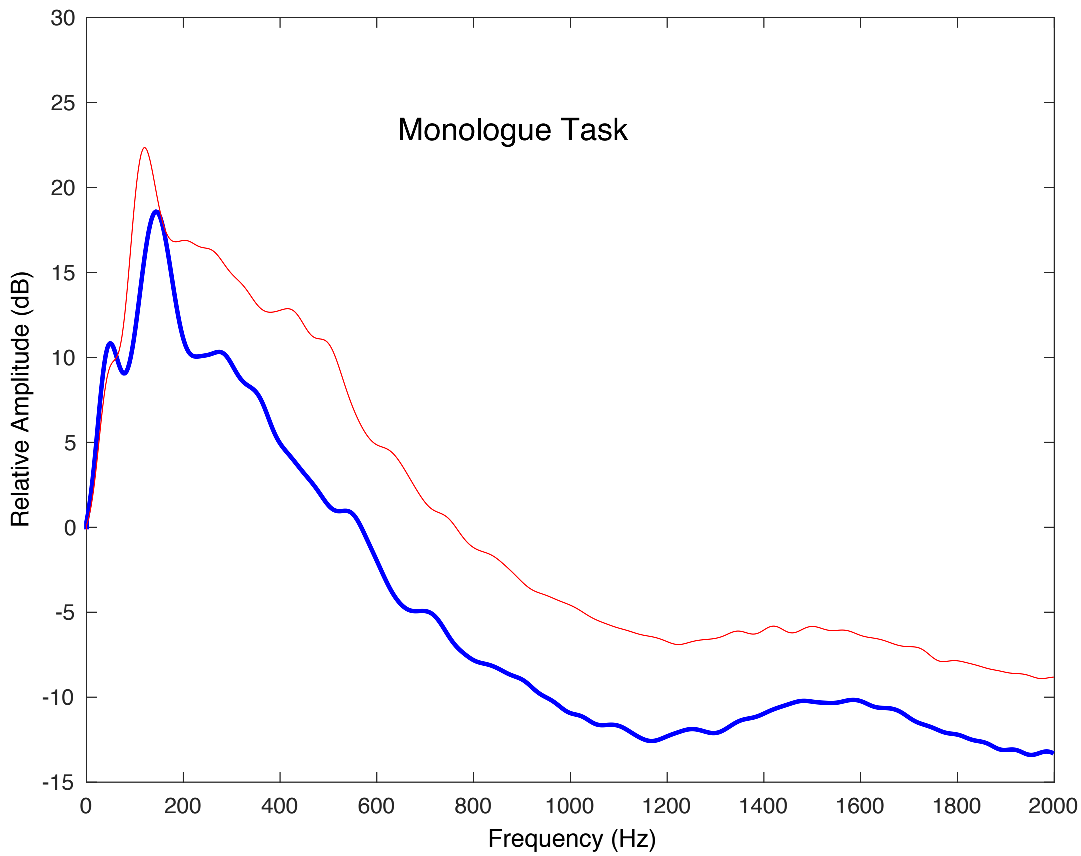
Figure 4. Long term average spectrum traces comparing PD and NN groups during the monologue task. Plots represent the mean for each group of 10 speakers and have been smoothed for clarity.


Speakers with PD
50
0
-50
0
500
1000
1500
2000

Neurologically normal speakers




Reading Task
Relative Amplitude (dB)
Frequency (Hz)
30
25
20
15
10
5
0
-5
-10
-15
0
200
400
600
800
1000
1200
1400
1600
1800
2000



Monologue Task
Relative Amplitude (dB)
Frequency (Hz)
30
25
20
15
10
5
0
-5
-10
-15
0
200
400
600
800
1000
1200
1400
1600
1800
2000