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Acoustic analysis of the tremulous voice: assessing the utility of the correlation dimension and perturbation parameters

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Abstract

Acoustic analysis may provide a useful means to quantitatively characterize the tremulous voice. Signals were obtained from 25 subjects with diagnoses of either Parkinson's disease or vocal polyps exhibiting vocal tremor. These were compared to signals from 24 subjects with normal voices. Signals were analyzed via correlation dimension and several parameters from the Multi-Dimensional Voice Program (MDVP): percent jitter, percent shimmer, amplitude tremor intensity index (ATRI), frequency tremor intensity index (FTRI), amplitude tremor frequency (Fatr), and fundamental frequency tremor frequency (Fftr). No significant difference was found between the tremor and control groups for ATRI and Fatr. Percent jitter, percent shimmer, FTRI, Fftr, and correlation dimension values were found to be significantly higher in the tremor group than in the control group. We conclude that these parameters may have utility for the clinical quantification of tremor severity and treatment effects.

Keywords

tremor; vocal polyps; Parkinson's disease; nonlinear dynamic analysis; correlation dimension; perturbation analysis; tremor parameters

11. INTRODUCTION

Tremor is physiologically defined as an involuntary periodic oscillation of a body part, such as the limbs, trunk, head, vocal folds, or facial structures, caused by contractions of antagonistic muscles. Physiological tremor is manifested in normal persons and is an asymptomatic oscillation, which is typically observed as having a small amplitude and high frequency (Jankovic and Fahn, 1980). In contrast, pathological tremor has been reported to have a lower frequency range and larger amplitude. This tremor is commonly diagnosed when it interferes with purposeful movement and is clinically visible or persistent (Findley, 1996). The exact pathophysiology of tremor is incompletely understood (Dromey and Smith, in press); however, several tremor types have been described in the literature. Postural tremor is found in essential tremor (ET), described as a monosymptomatic tremor without other neurological signs

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(Findley and Koller, 1987). Resting tremor is most commonly associated with Parkinson's disease (PD) and is associated with progressive lesions of the basal ganglia. Intention tremor, often found in multiple sclerosis, is generally related to cerebellar disease (Jiang et al., 2000).

Patients with vocal tremor are unable to voluntarily produce steady, sustained phonation and may present with complaints of wobbly or shaky voice. Severe tremor may result in abrupt stoppage of voice, which is characteristic of spasmodic dysphonia (Colton and Casper, 1996). Tremulous voice can result from tremor isolated to the glottis and the muscles of phonation or can occur in conjunction with tremor of head and neck muscles or other body parts. Some research has suggested that vocal tremor may originate from modulation of the vocal tract rather than modulation of the laryngeal musculature (Jiang et al., 2000), and only slight evidence of highly correlated laryngeal muscular activity leading to vocal tremor has been found (Finnegan et al., 2003).

This study is concerned with the tremulous voice manifested via two etiologies, PD and vocal fold polyps. PD is a neurological disease resulting from the degeneration of dopaminergic neurons in the basal ganglia. Hallmark symptoms include rigidity, postural instability, bradykinesia, and resting tremor, which is the initial symptom in 70% of individuals diagnosed with PD (Findley, 1996). Approximately 60-90% of PD patients exhibit some form of vocal impairment, such as vocal tremor (Jiang et al., 1999; Perez et al., 1996). Vocal fold stiffness, vocal fold bowing, and incomplete glottal closure are often seen in PD, causing changes in vocal fold mass and tension (Perez et al., 1996; Rahn III et al., 2007). These changes, which are accompanied by a progressive breakdown of coordinated motor control, result in vibrational phase asymmetry that causes vocal tremor. Vocal polyps are benign mass lesions of the vocal fold lamina propria typically occurring unilaterally. These lesions often result in a perceptual quality of roughness or hoarseness during phonation (Chagnon and Stone, 2000). Polyps can introduce nonlinear stiffness and collision to the vocal folds and cause incomplete glottal closure and asymmetric vocal fold vibration (Zhang and Jiang, 2004). These irregular characteristics of vocal fold vibration with a vocal polyp can contribute low-frequency modulations to the vocal signal similar to those present in PD and may lead to tremulous voice of non-neurological origin.

Acoustic analysis has been applied previously to quantitatively characterize the tremulous voice. Perturbation analysis has demonstrated that tremulous voices have higher jitter and shimmer, lower harmonic-to-noise ratio, and higher long-term frequency and amplitude modulation than normal voices (Ramig and Shipp, 1987; Gamboa et al., 1998; Winholtz and Ramig, 1992; Aronson et al., 1992). Further, frequency and amplitude of tremor may be altered by disease progression (Elble, 1986). Most researchers have found shimmer to be more reliable than jitter in the analysis of vocal tremor (Gonzalez et al., 2002; Kent et al., 2003). However, recent research suggests that the validity of perturbation analysis is questionable when measures are applied to aperiodic signals (Titze, 1995; Karnell et al., 1995; Holmes et al., 2000). Nonlinear dynamic analysis has been applied previously to study PD (Zhang et al., 2005) and vocal mass lesions (Zhang and Jiang, 2004; Zhang et al., 2004) and has shown potential to reliably quantify both periodic and aperiodic signals.

In this study, short- and long-term frequency and amplitude perturbation parameters measured by the Multi-Dimensional Voice Program (MDVP; Kay Elemetrics Corp., 1993) and the nonlinear dynamic parameter of correlation dimension were applied to tremulous voices from subjects with PD and vocal polyps and normal voices from healthy subjects. Acoustic analysis results from subjects with PD and subjects with vocal polyps were compared to confirm that the tremulous voices resulting from these two pathologies were not significantly different. Perturbation and nonlinear dynamic parameters of tremor and normal voice groups were also compared to determine their distinct abilities to differentiate normal from pathological tremor.

It was hypothesized that tremulous voices from these two pathologies would not produce significantly different acoustic analysis results and that MDVP and nonlinear dynamic analyses would demonstrate an ability to significantly differentiate between normal and tremulous voice.

2. MATERIALS AND METHODS

2.1 Subjects

The University of Wisconsin Institutional Review Board approved the human subjects protocol and consent procedure used in this study. All 49 volunteer subjects were rigorously examined before voice recordings. The medical histories of subjects with PD complaining of voice deterioration were examined, and PD subjects underwent clinical examination by an attending neurologist to confirm that they exhibited the main symptoms of PD. It was also confirmed by an otolaryngologist that these patients exhibited no vocal pathologies except those resulting from PD. Subjects with vocal polyps underwent examination by an otolaryngologist to confirm the presence of polyps and the absence of any additional voice pathologies. Control subjects were also examined to ensure that all had normal, non-pathological voices. After examination, 25 subjects with vocal tremor were included in this study: 15 subjects with PD and 10 subjects with vocal polyps (13 females, 12 males). Twenty-four control subjects with normal voices (13 females, 11 males) were included.

2.2 Recording procedure and signal processing

A close-fitting facemask was used to capture recordings, with a condenser microphone (AKG Acoustics, Vienna, Austria) placed 15 cm from the subjects' mouths. Subjects were asked to sustain steady phonation of the vowel /i/ at a comfortable pitch for two to three seconds at an intensity of 80 dB. This procedure was repeated until three signal recordings were made at a sampling rate $f_s = 20$ kHz using a 12-bit analog-to-digital converter (National Instruments AT-MIO-16, Austin, TX). A stationary segment, $x(t_i)$, $t_i = i\Delta t$, $\Delta t = 1/f_s$, $i = 1, 2, \dots$, one second in length was selected for analysis from each recording, omitting voice onset and offset to avoid effects of speech intonation or interactions between the larynx and vocal tract on analysis.

2.3 Acoustic analysis with the Multi-Dimensional Voice Program

The Multi-Dimensional Voice Program (MDVP, Model 4300, KayPENTAX, Lincoln Park, NJ) was applied for multi-parametric acoustic analysis of voice. Perturbation parameters of percent jitter and percent shimmer, which measure cycle-to-cycle frequency and amplitude variation of a voice signal, respectively, were collected for this study.

MDVP includes four parameters intended to analyze different qualities of vocal tremor. The amplitude tremor intensity index (ATRI) is the average ratio of the amplitude of the most intense low-frequency amplitude-modulating component to the total signal amplitude. The frequency tremor intensity index (FTRI) is the average ratio of the frequency magnitude of the most intense low-frequency-modulating component to the total frequency magnitude of the signal. Amplitude tremor frequency (Fatr), measured in Hz, is the frequency of the most intense low-frequency amplitude-modulating component in a specified analysis range. Fundamental frequency tremor frequency (Fftr), also measured in Hz, is the frequency of the most intense low-frequency fundamental frequency-modulating component in a specified analysis range. While perturbation parameters are intended to measure short-term variability of the voice signal, these four tremor parameters aim to measure long-term signal variability indicative of tremor (Kay Elemetrics Corp., 1993). ATRI, FTRI, Fatr, and Fftr were calculated for all signals.

2.4 Nonlinear dynamic analysis

The nonlinear dynamic parameter of correlation dimension (D_2) was calculated for all signals. D_2 is a measure of chaotic complexity which specifies the number of degrees of freedom needed to describe a system, such that a system with greater complexity has a higher dimension and requires additional degrees of freedom to describe its dynamic state (Grassberger and Procaccia, 1983). $D_2 = 0$ denotes a static state, $D_2 = 1$ denotes a perfectly periodic oscillation, $D_2 = 2$ denotes a quasi-periodic tori, described as a superposition of two or more oscillations with no rational fundamental frequencies or biphonation, and a fractal D_2 value denotes an aperiodic or chaotic oscillation. In this study, D_2 calculations were performed using custom nonlinear dynamic analysis software developed by the Laryngeal Physiology Laboratory at the University of Wisconsin School of Medicine and Public Health. Calculations made by the software were drawn from numerical algorithms that have been applied previously to analyze excised larynx phonations (Jiang et al., 2003) and human voices (Jiang and Zhang, 2002; Zhang et al., 2004; Zhang et al., 2005). These calculations are briefly summarized here.

Nonlinear dynamic methods, including phase space and D_2 , can be applied to describe chaotic activities. In a vibratory system, such as the vocal folds, phase space is defined by many dynamic variables defining positions and velocities. Over time, vibration of the vocal folds can be shown as a trajectory in phase space, which, after an initial transient, asymptotically approaches an invariant set, or attractor (Zhang et al., 2005; Herzel et al., 1994; Titze, 1994).

First, the time delay technique is applied to reconstruct the dynamics of a signal in m -dimensional delay-coordinate phase space from measured experimental data. The time delay is described as $\mathbf{X}_i = \{x(t_i), x(t_i - \tau), \dots, x(t_i - (m-1)\tau)\}$ (Packard et al., 1980), where m is the embedding dimension and τ the time delay. To determine m , the embedding theorem is used (Takens, 1981), and when $m > 2D+1$, where D is the Hausdorff dimension, the reconstructed phase space is topologically equivalent to the original phase space. The proper τ is estimated using the mutual information method (Fraser and Swinney, 1986), where the first minimum value of the mutual information function provides an appropriate measure for τ . Choosing the proper τ is important for phase space reconstruction; if τ is too small, the reconstructed attractor is stretched around a diagonal line, and if τ is too large, the reconstructed attractor displays self-intersection. Via these methods, vocal dynamics can be studied in reconstructed phase space. A periodic trajectory is closed in its reconstructed phase space, while a chaotic trajectory is noiselike and irregular in its reconstructed phase space.

The correlation dimension is defined as $D_2 = \lim_{r \rightarrow 0} \frac{\log C(r)}{\log r}$ and is applied to reveal the geometrical scaling property of the attractor. The correlation integral

$C(W, N, r) = \frac{2}{(N+1-W)(N-W)} \sum_{n=W}^{N-1} \sum_{i=0}^{N-1-n} \theta(r - \|\mathbf{X}_i - \mathbf{X}_{i+n}\|)$ is applied, where r is the radius around $\mathbf{X}_i$, W is set to be the time delay τ , and $\theta(x)$, the Heaviside step function, is defined

by $\theta(x) = \begin{cases} 1 & x > 0 \\ 0 & x \leq 0 \end{cases}$, using the improved algorithm proposed by Theiler. This formula eliminates all sets of vectors that lie within W of each other, where W is set to be the proper time delay τ . $C(W, N, r)$ is used to measure the number of distances between points in reconstructed phase space that are smaller than the r . In the curve of $\log C(W, N, r)$ versus $\log r$, if r were too small, random noise would dominate such that D_2 would continue to increase with m . If r were too large, all points in the reconstructed phase space would be smaller than r such that D_2 would approach zero. A finite region exists between these two extremes, the scaling region, in which the slopes of $\log C(W, N, r)$ versus $\log r$ increase at first but eventually converge with increasing m . As m increases, D_2 and its standard deviation can be estimated with a linear curve fit to the slopes of $\log_2 C(r)$ versus $\log_2 (r)$ in the scaling region of r

(Grassberger and Procaccia, 1983). For a substantially large m , a small standard deviation of the slope within the scaling region demonstrates a reliable D_2 estimation of the chaotic time series. Standard deviation of D_2 measurement was maintained at 5% or less to ensure the reliable calculation of D_2 .

2.5 Statistical analysis

SigmaPlot 8.0 and SigmaStat 3.0 software (Jandel Scientific, San Rafael, CA) were used to statistically analyze and graph acoustic analysis data from control, PD, and vocal polyp group subjects. Because it could not be assumed that the data were drawn from a normally distributed population with equal variance, the nonparametric Mann-Whitney rank sum test was applied for analysis. Statistical significance was set at the $p = 0.05$ level for all tests. Bonferroni adjustments were not applied due to serious implications of significant type II error inflation (Nakagawa, 2004).

3. RESULTS

The typical waveforms for a normal voice from a healthy subject and a tremulous voice from a subject with vocal polyps are shown in Figure 1(a) and 1(b), respectively. The normal voice produced a nearly periodic waveform. Percent jitter and percent shimmer were measured as 0.398 and 0.683, respectively. ATRI and Fatr were both 0 for this normal voice, while FTRI and Fftr were calculated as 0.242 and 2.198 Hz, respectively. D_2 for this normal voice was estimated as 1.318 ± 0.007 . The tremulous voice produced an irregular waveform, indicative of potential pitch period extraction difficulties for linear acoustic analysis. Percent jitter and percent shimmer were 0.686 and 2.041, respectively. ATRI was measured as 8.539, while FTRI was measured as 0.886 for this tremulous voice. Fatr and Fftr values were 7.843 Hz and 4.706 Hz, respectively. D_2 for this pathological signal was estimated as 2.224 ± 0.012 . It appeared that the tremulous voice demonstrated significantly higher perturbation values, tremor parameter values, and nonlinear dimensionality than the normal voice. To evaluate these findings from typical signals, comparisons among PD, vocal polyp, and control group signals were made.

Mann-Whitney rank sum testing was first applied to assess the null hypothesis that the two pathologies represented in the tremor group, PD and vocal polyps, did not produce significantly different acoustic analysis results. For all measured acoustic parameters (percent jitter, percent shimmer, ATRI, FTRI, Fatr, Fftr, and D_2) tremulous signals generated by subjects with PD and tremulous signals generated by subjects with vocal polyps were not significantly different. Results of Mann-Whitney rank sum tests between PD and vocal polyp groups are given in Table 1.

Acoustic analysis results are summarized in Table 2. Mann-Whitney rank sum tests revealed that values of percent jitter and percent shimmer were significantly higher for the PD and vocal polyp groups than for the control group ($p = 0.019$ and $p = 0.008$, respectively) [Table 1, Fig. 2]. Results of tremor parameter analysis for tremor and control group voices were mixed. Of the four parameters, FTRI and Fftr showed significant intergroup differences, with PD and vocal polyp groups' signals demonstrating significantly greater FTRI and Fftr than control group signals ($p = 0.036$ and $p = 0.023$, respectively) [Fig. 3(b),(d)]. The PD and vocal polyp groups and the control group were not significantly differentiated using tremor measures of ATRI and Fatr ($p = 0.183$ and $p = 0.09$, respectively) [Fig. 3(a),(c)]. D_2 analysis results showed that the PD and vocal polyp groups had significantly greater D_2 values than the control group ($p = 0.004$) [Fig. 4].

4. DISCUSSION

Quantitative acoustic analysis has previously been applied to describe pathological human voices (Dromey and Smith, in press; Zhang et al., 2005; Rahn III et al., 2007; Ramig and Shipp, 1987; Gamboa et al., 1998; Gonzalez et al., 2002; Kent et al., 2003; Holmes et al., 2000; Jiang and Zhang, 2002) and to document treatment effects for pathological voices (Zhang et al., 2004). It is necessary to establish the utility of acoustic analysis methods for the measurement of tremulous voice in order to enhance understanding of the qualities of this pathological voice type. By testing the capabilities of traditional perturbation and tremor parameters from MDVP, as well as nonlinear dynamic parameters, we aimed to elucidate the efficacy of certain parameters to aid clinicians in the characterization of tremulous voice.

None of the seven acoustic analysis parameters applied in this study were capable of significantly differentiating between tremulous signals produced by subjects with PD and tremulous signals produced by subjects with vocal polyps. This result serves to indicate the difficulty of applying acoustic analysis to differentiate tremor etiologies. Out of the applied acoustic measures, D_2 came the closest to significantly differentiating tremulous voice from PD and tremulous voice from vocal polyps ($p = 0.071$).

In previous years, reliability of results has become a major concern in the use of acoustic analysis techniques relying on pitch extraction for the analysis of aperiodic voices (Titze, 1995; Karnell et al., 1995; Holmes et al., 2000). Because MDVP does not have an internal measurement of error, as does another program relying on pitch extraction, CSpeech (Milenkovic and Read, 1992), it is not possible to quantify the extent of error present in MDVP acoustic analysis results. Therefore, although MDVP was capable of analyzing all voice samples in this study, the results of acoustic analysis generated from tracking pitch periods should be approached with caution.

Results of percent jitter and percent shimmer analysis in this study corroborate previous studies investigating perturbation parameters of the tremulous voice, in that short-term amplitude and frequency variation are significantly higher in the tremulous voice than the normal voice (Jiang et al., 1999; Gamboa et al., 1998; Ramig and Shipp, 1987; Aronson et al., 1992). Further, greater variability in percent jitter and percent shimmer is evident in the tremulous voices, as demonstrated by the standard deviations of these measures [Figure 2]. This finding highlights the instability of tremor in voice and echoes the finding of greater range of short-term frequency and amplitude modulation in tremulous voices found in previous studies (Ramig and Shipp, 1987; Aronson et al., 1992).

Previous acoustic analysis research employing the MDVP software has largely overlooked the application of tremor parameters. In applying various MDVP parameters to PD and control groups, PD subjects were previously found to be different from the control group mainly in fundamental frequency and frequency perturbation parameters, rather than the tremor parameters (Kent et al., 2003). One study concluded that the tremor parameters were the least reliable of any MDVP parameters (Gonzalez et al., 2002). The algorithm employed for tremor analysis detects the strongest long-term periodic frequency and amplitude modulations of a signal. The magnitudes of these modulations are quantified by ATRI and FTRI. If the magnitudes of tremor are above a set low detection threshold, Fatr and Fftr provide quantitative information about the rates of change in tremor frequency and amplitude, respectively (Kay Elemetrics Corp., 1993).

In this study, significant differences in tremor parameters between the tremor and control groups were only found for measures of frequency. While all tremor parameters had large standard deviation values, this variability was greatest for measures of tremor amplitude. Further, many signals had ATRI and Fatr values of 0, which may explain statistical

insignificance between tremor and control groups for these measures. Median values of ATRI and Fatr for both groups are 0 [Figure 3(a) and (c)].

Previously, nonlinear dynamic analysis has been effective for the quantification of complexity in disordered voices (Zhang et al., 2005; Rahn III et al., 2007; Zhang et al., 2004; Jiang and Zhang, 2002). Nonlinear dynamic measures, such as the D_2 parameter applied to tremulous and normal voices in this study, afford a advantage over traditional perturbation measures of voice in that the parameters do not require demarcation of regular cycles in the temporal domain ($p = 0.004$) [Figure 4]. Tremor generated irregularities in the signal which caused a significant increase in signal dimensionality. This and other nonlinear dynamic parameters may be valuable for application with existing quantitative and qualitative techniques to describe the nature of tremor in voice.

5. CONCLUSIONS

In this study, percent jitter, percent shimmer, ATRI, FTRI, Fatr, and Fftr from MDVP and D_2 were calculated for normal voices from healthy subjects and tremulous voices from subjects with PD or vocal polyps. No significant differences were found for any parameter between tremulous voices from different etiologies. Percent jitter and percent shimmer were significantly higher in the tremor group. Tremor parameters of FTRI and Fftr, which measure long-term tremor frequency modulation, were also significantly higher in the tremor group. The nonlinear dynamic parameter D_2 was effective in differentiating normal from tremulous voices. The application of perturbation measures, long-term tremor measures, and nonlinear dynamic parameters may be further examined in the future for the quantification of tremor severity and for the documentation of treatment effects for tremor.

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APPENDIX A

Continuing education

1. According to the literature, how can one distinguish pathological tremor from physiological tremor?
 - a. Pathological tremor has a lower frequency range than physiological tremor.
 - b. Pathological tremor has a small amplitude.
 - c. Pathological tremor does not interfere with purposeful movement.
 - d. Both (a and c).
2. Which of the following statements is/are true regarding the nonlinear dynamic parameter of correlation dimension?
 - a. Correlation dimension estimation describes the complexity of a dynamic system.
 - b. Correlation dimension algorithms do not require calculation of pitch periods for reliable analysis results.
 - c. Correlation dimension analysis can only be applied to analyze nearly periodic signals.

- d. Both (a and b).
 - e. None of the above.
3. How are the MDVP tremor parameters different from the perturbation parameters of jitter and shimmer?
- a. Jitter and shimmer measure short-term variability of the voice signal, whereas tremor parameters do not.
 - b. Tremor parameters measure amplitude and frequency properties of a signal, whereas jitter and shimmer do not.
 - c. Tremor parameters measure short-term variability of the signal, whereas jitter and shimmer parameters do not.
 - d. None of the above.
4. Which of the following statements is/are true regarding the MDVP tremor parameters as applied in this study?
- a. Tremulous voice resulting from Parkinson's disease and tremulous voice resulting from vocal polyps were not significantly differentiated using tremor parameters.
 - b. Tremor group signals demonstrated significantly greater FTRI than control group signals.
 - c. Tremor group signals demonstrated significantly greater Fftr than control group signals.
 - d. All of the above.
5. True/False: In this study, correlation dimension was ineffective in differentiating normal from tremulous voice; therefore, the parameter may not be a stable measure of the tremulous qualities of the voice signal.

Answer key:

- 1. a
- 2. d
- 3. a
- 4. d
- 5. False

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Figure 1.

Acoustic waveform of (a) a typical normal voice from a healthy subject and (b) a typical tremulous voice from a subject with vocal polyps.

Figure 2.

Distributions of perturbation analysis results for (a) percent jitter and (b) percent shimmer from Parkinson's disease (PD), vocal polyp (VP), and control groups. The line inside the box marks the median, whiskers show 10th and 90th percentiles, and the dots are the outlying points.

Figure 3.

Distributions of tremor parameter analysis results for (a) amplitude tremor intensity index (ATRI), (b) frequency tremor intensity index (FTRI), (c) amplitude tremor frequency (Fatr), measured in Hz, and (d) fundamental frequency tremor frequency (Fftr), measured in Hz from Parkinson's disease (PD), vocal polyp (VP), and control groups. The line inside the box marks the median, whiskers show the 10th and 90th percentiles, and the dots are the outlying points.

Figure 4. Distribution of correlation dimension (D_2) from Parkinson's disease (PD), vocal polyp (VP), and control groups. The line inside the box marks the median, whiskers show the 10th and 90th percentiles, and the dots are the outlying points.

Table 1

Results from Mann-Whitney rank sum testing of Parkinson's disease (PD) group vs. vocal polyp group and tremor vs. control groups for the following parameters: percent jitter, percent shimmer, amplitude tremor intensity index (ATRI), frequency tremor intensity index (FTRI), amplitude tremor frequency (Fatr), fundamental frequency tremor frequency (Fftr), and correlation dimension (D_2). Results are summarized here in the form of p values.

	PD vs. Vocal Polyp	Tremor vs. Control
Percent jitter	$p = 0.598$	$p = 0.019$
Percent shimmer	$p = 0.212$	$p = 0.008$
ATRI (%)	$p = 0.677$	$p = 0.183$
FTRI (%)	$p = 0.487$	$p = 0.036$
Fatr (Hz)	$p = 0.232$	$p = 0.090$
Fftr (Hz)	$p = 0.677$	$p = 0.023$
D_2	$p = 0.071$	$p = 0.004$

Table 2

Mean (M) and standard deviation (SD) of percent jitter, percent shimmer, amplitude tremor intensity index (ATRI), frequency tremor intensity index (FTRI), amplitude tremor frequency (Fatr), fundamental frequency tremor frequency (Fftr), and correlation dimension (D_2) for Parkinson's disease (PD), vocal polyp (VP), and control groups.

	PD group	VP group	Control group
Percent jitter	M = 0.804	M = 0.845	M = 0.483
	SD = 0.597	SD = 0.535	SD = 0.209
Percent shimmer	M = 1.909	M = 1.470	M = 1.045
	SD = 1.187	SD = 1.121	SD = 0.848
ATRI (%)	M = 0.572	M = 0.445	M = 0.417
	SD = 0.817	SD = 0.292	SD = 1.005
FTRI (%)	M = 2.409	M = 1.545	M = 0.157
	SD = 3.141	SD = 2.777	SD = 0.25
Fatr (Hz)	M = 2.842	M = 3.760	M = 1.106
	SD = 3.817	SD = 2.346	SD = 2.338
Fftr (Hz)	M = 3.005	M = 2.286	M = 1.154
	SD = 3.467	SD = 3.065	SD = 1.46
D_2	M = 2.047	M = 1.718	M = 1.575
	SD = 0.385	SD = 0.435	SD = 0.276