Acoustic Analysis of the Voice in Patients with Parkinson's Disease and Hypokinetic Dysarthria

Sara Fernández García [a], Cristina Gabriela Dumitrache Dumitrache [b] y José Andrés González López [c]

a Clínica de Logopedia de la Complutense, Campus de Somosaguas, Universidad Complutense de Madrid, 28223, Pozuelo de Alarcón, Madrid, España

b Departamento de Psicología Evolutiva y de la Educación, Facultad de Psicología, Campus de La Cartuja S/N, Universidad de Granada, 18071, Granada, España

c Departamento de Teoría de la Señal, Telemática y Comunicaciones, ETS de Ingenierías Informática y de Telecomunicación, Universidad de Granada, 18071, Granada, España

Email: sarafern16@ucm.es; ncalet@ugr.es; joseangl@ugr.es

Autor de correspondencia: José A. González (joseangl@ugr.es) Departamento de Teoría de la Señal, Telemática y Comunicaciones, ETS de Ingenierías Informática y de Telecomunicación, Universidad de Granada, 18071, Granada, España.

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Conflicto de intereses

Los autores son responsables de la investigación aquí descrita y han participado en el diseño, análisis e interpretación de los datos, redacción o revisión del manuscrito, y han aprobado el manuscrito tal como se presenta. Los autores no tienen ningún conflicto de intereses que pueda interpretarse como una influencia en la investigación.

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Abstract

Background and aim: Most patients with Parkinson's disease (PD) develop speech disorders during the course of the disease. These disorders severely affect speech intelligibility and vocal quality of these people. The aim of this work is to characterize the voice and speech of subjects with PD through the automatic analysis of voice recordings. We also study whether there is a relationship between the acoustic parameters extracted from the recordings and the quality of the voice perceived by the subjects themselves.

Materials and methods: This is a descriptive correlational study in which 20 subjects with PD and 20 healthy controls were compared. The subjects with PD completed the VHI-30 instrument and performed sustained phonation of different vowels in Spanish. The stage of the disease was also evaluated using the Hoehn and Yahr scale.

Results: There are greater vocalic changes in subjects with PD than in healthy controls. In particular, significant differences were found for the vowel space area, intensity, F0, jitter and shimmer. No statistically significant associations were found between these acoustic parameters and the voice quality as perceived by the subjects with PD.

Conclusions: Acoustic analysis of voice and speech may be of great help in characterizing the state of hypokinetic dysarthria in PD patients. In addition, automatic tools of this type could be used in the future in a complementary manner to facilitate identifying treatments needs in PD patients.

Keywords: Parkinson's, hypokinetic dysarthria, acoustic speech analysis, vowel space area.

Resumen

Antecedentes y objetivo: La mayoría de pacientes con enfermedad de Parkinson (EP) desarrollan trastornos del habla durante el curso de la misma. Estos trastornos afectan gravemente la inteligibilidad del habla y la calidad vocal de estas personas. El objetivo de este trabajo es caracterizar la voz y el habla de personas con EP mediante el análisis automático de grabaciones de voz. También se estudia si existe la relación entre los parámetros acústicos extraídos de las grabaciones y la calidad de la voz percibida por los propios sujetos.

Materiales y métodos: Se trata de un estudio descriptivo correlacional en el que se compararon 20 sujetos con EP y 20 controles sanos. Los sujetos con EP completaron el instrumento VHI-30 y realizaron fonación sostenida de distintas vocales en español. Asimismo, se evaluó el estadio de la enfermedad utilizando la escala de Hoehn y Yahr.

Resultados: Hay mayores cambios vocálicos en las personas con EP que en los controles sanos. En particular, se encontraron diferencias significativas para el área del espacio vocálico, la intensidad, F_0, el *jitter* y el *shimmer*. No se encontraron asociaciones estadísticamente significativas entre esos parámetros y la calidad de voz percibida por el propio sujeto.

Conclusiones: El análisis acústico de la voz y el habla puede ser de gran ayuda para caracterizar el estado de la disartria hipocinética en pacientes con EP. Además, este tipo de herramientas automáticas podrían facilitar la detección de necesidades de tratamiento de los pacientes con EP.

Palabras clave: Enfermedad de Parkinson, disartria hipocinética, análisis acústico de la voz, área del espacio vocálico.

Introduction

Parkinson's disease (PD) is a neurodegenerative disease of the central nervous system (CNS) characterized by the progressive loss of dopaminergic neurons in the substantia nigra (Zarzur, Duprat, Shinzato, & Eckley, 2007). The main cause of this disease remains unknown, although it is thought that the origin is "multi-causal", that is, there are exogenous, endogenous and genetic factors related to the origin of the disease (Sveinbjornsdottir, 2016).

PD is the second most common neurodegenerative disorder after Alzheimer's disease (Aarsland, Påhlhagen, Ballard, Ehrt, & Svenningsson, 2012). In Europe, it is estimated that 15 new cases occur per 100,000 inhabitants per year (Tysnes & Storstein, 2017). PD affects both genders equally, although most studies indicate a slight male predominance (Hirsch, Jette, Frolkis, Steeves, & Pringsheim, 2016). The mean age of the patients when PD is diagnosed is 55 years-old and the majority of them are between 50 and 80 years of age (Pringsheim, Jette, Frolkis, & Steeves, 2014).

PD is a neural disease of slow progression that is clinically characterized by tremor at rest, bradykinesia, muscular rigidity and postural instability (Rusz, Čmejla, Růžičková, & Růžička, 2011). Swallowing, cognition and speech problems are often relegated to the background in these patients. However, it has been shown that 90% of patients will develop speech problems during the course of the disease (Miller et al., 2007; Perez-Lloret et al., 2012). Furthermore, patients with PD usually suffer from depression, whose origin is believed to be "multi-causal" (McLaughlin et al., 2011). One of the causes is related to the vocal alterations caused by this disease (Sapir, 2014). Depression is known to have a direct impact on the quality of life of PD patients and their relatives and is associated with worse functional and cognitive performance (Leiknes, Tysnes, Aarsland, & Larsen, 2010).

One of the characteristic features of PD is the modification of voice and speech (Mate, Cobeta, Jiménez-Jiménez & Figueiras, 2012). During the course of the disease PD patients can develop hypokinetic dysarthria (Rusz et al., 2011), which is a disorder of verbal expression caused by an alteration in the muscular control of the speech organs. It is described as a slow, weak and monotonous speech, comprising motor dysfunctions in respiration, phonation, resonance, articulation and prosody (Duffy, 2013). The acoustics of dysarthric speech reflect the physiological and anatomical changes caused by Parkinson's. Firstly, the changes in the respiratory system affect the vocal intensity of the patients (Watts, 2016). Secondly, the changes in the phonatory system mainly affects the vibratory rhythm of the vocal folds, which results in an increase of the fundamental frequency (F_0) and an alteration of the prosody (Sveinbjornsdottir, 2016). Finally, the articulatory system is also affected, resulting in articulatory inaccuracies and an increase in the number of pauses (Watts, 2016). Changes in voice intensity and quality are common early symptoms of dysarthric speech that can be detected in the pre-diagnosis period (Oguz et al., 2006), while changes in articulation are more likely to appear at a later stage (Wight & Miller, 2015). Despite these problems, PD patients are not aware that their voice is weak, nor that the voice progressively weakens if they do not make a constant effort during speech (Bermúdez de Alvear & Martínez Arquero, 2013; Midi et al., 2008).

Individuals with PD have greater vocalic changes compared to healthy controls when the voice is analyzed either perceptually or acoustically (Rodrigues das Graças, Côrtes Gama, Costa Cardoso, Pereira Lopes, & Barreto Bassi, 2012). Speech can be a valuable marker of disease progression and treatment efficacy in PD (Rusz et al., 2013). Therefore, the assessment of individual’s voice through the analysis of the acoustic signal could facilitate the early diagnosis of PD (Tanaka, Nishio, & Niimi, 2011).

However, research on the development and progression of dysarthria in patients with PD is scarce (Skodda, Grönheit, Mancinelli, & Schlegel, 2013). When attempting to detect and characterize pathological voices, the aim is to analyze their differences with respect to healthy voices (Elisei, 2012). In this sense, several studies have shown that acoustic parameters such as the fundamental frequency (F_0), intensity, jitter (variation of F_0 in time), shimmer (variation of voice intensity over time) and the noise to harmonic ratio (NHR) (relative amount of additive noise in the voice signal due to turbulent airflow generated by inadequate closure of the vocal folds) are affected in pathological voices (Núñez-Batalla et al., 2007). These parameters have been also employed to describe the voices of individuals with PD. For instance, in a previous investigation it was found that the voice tone and intensity in women with PD vanishes over time (Sabine Skodda, Rinsche, & Schlegel, 2009). Also, it was reported that the jitter is also affected in patients with PD (Bang, Min, Sohn, & Cho, 2013; Rodrigues das Graças et al., 2012; Tanaka et al., 2011). However, there are contradictions as to whether the shimmer is also affected or not in these patients (Bang et al., 2013; Rodrigues das Graças et al., 2012). Regarding the NHR, while most previous studies found no significant differences between PD patients and healthy controls for this parameter (Bang et al., 2013; Rodrigues das Graças et al., 2012; S Skodda et al., 2013), Tanaka *et al.* (2011) reported significant differences between both groups in the NHR.

Another index used in the objective evaluation of dysarthria is the vowel space area (VSA), which is the area of the polygon formed by the vowels in the 2-dimensional space defined by their two first formant frequencies (Delgado-Hernández, 2017). This parameter is known to be affected in dysarthric speakers (Kim, Hasegawa-Johnson & Perlman, 2012; Landsford & Liss, 2014; Liu, Tsao, & Kuhl, 2005; McRae, Tjaden & Schoonings, 2002; Weisme, Jeng, Laures, Kent & Kent, 2001; Turner, Tjaden, &

Weismer, 1995). However, there is no consensus regarding whether this parameter is related to speech intelligibility. Several studies have reported statistically positive relations between the VSA and the level of speech intelligibility (Landsford & Liss, 2014; McRae, Tjaden & Schoonings, 2002; Weisme et al., 2001), but this relation was not found to be significant in other study (McRae et al., 2002) . This variability of results could be explained by the high sensitivity of the VSA to intersubject variability (Sapir, Ramig, Spielman & Fox, 2010).

To shed more light on the effects of PD on the voice of individuals suffering from this disease, in this study we compared the voices of PD patients with that of healthy controls using acoustic parameters computed from voice recordings. We recorded vocalizations of the five vowels in Spanish (/a/, /e/, /i/, /o/, /u/) for both subject groups and then computed a set of objective parameters from the recordings: F_0, jitter, shimmer, NHR, the first two speech formant frequencies F1 and F2 (the resonances of the vocal tract) and the vowel space area (the area of the quadrilateral formed by the vowels when they are projected onto the plane defined by their F1/F2 formants). Statistical analyses were then performed to determine the parameters that are more affected by PD in order to relate those changes with the effects produced by dysarthria. Furthermore, we also investigated the relation between the patient's self-perception of her/his voice and the acoustic parameters.

Method

Subjects

In this study, 20 patients with PD, 12 men and 8 women, were recruited. The mean age of the men was 78.58 years (SD: 6.52; range: 65-93) and 73.38 years (SD: 6.55; range: 66-85) for the women. The inclusion criteria for the experimental group were to

be native Spanish speakers, do not have any other diseases of interest, have been diagnosed with PD for more than a year and receiving speech therapy support at the time of the study. PD was diagnosed by a neurologist and the patients were all treated with antiparkinsonian medications. The control group consisted of 20 healthy subjects, 12 men and 8 women. The mean age of the men was 71.50 years (SD: 3.92; range: 66-77) and 67.78 years (SD: 4.49; range: 62-74) for the women. The exclusion criteria for this group were: having a record of voice disorders or associated neurological disorders, not native Spanish speaker and having performed speech therapy.

Experimental procedure

Each subject performed the sustained phonation of the five vowels in Spanish (/a/, /e/, /i/, /o/ and /u/) for at least five seconds at a comfortable tone and loudness in an acoustically isolated room. When the recordings were performed the participants with PD were in the ON phase. The majority of previous investigations were carried out with English or American patients while in our study we analyzed vocalizations of Spanish patients. In addition, most of the previous investigations only analyzed the vocalization of the /a/ vowel (Jaywant & Pell, 2010; Rodrigues das Graças et al., 2012; Skodda et al., 2013; Tanaka et al., 2011), but the five Spanish vowels were analyzed in this study. The study of the five vowels gives us more information about articulatory schemes in various articulatory positions. Also, the study of vowels presents certain advantages over consonants because of their greater stability against the change of the acoustic components. Thus, each vowel has different vowel features, open /a/ centered, the /e/ half-closed, the /i/ closed and anterior, the /o/ half-closed and posterior (rounded) and the /u/ closed and posterior (rounded) (Quilis, 1981). The vocalizations were recorded with an Olympus WS-110 recorder at a distance of about 30 cm from the oral cavity. The acoustic analysis was performed using Praat software version 5.6.56 for Windows. The beginning

and the end of each phonation was discarded in order to analyze the segment of greater acoustic stability.

Instruments

Hoehn and Yahr scale

The Hoehn and Yahr scale (Hoehn & Yahr, 1967) is a descriptive scale that provides an overall estimate of clinical function in PD. Although it was originally developed as a five-point scale (1-5), there are adaptations introducing 0.5-point increments (Goetz et al., 2004). The classical 5-point scale shown in table 1 was used in the present investigation as it is the most widely used version.

Table 1. Hoehn and Yahr scale.

Stage	Hoehn and Yahr scale
1	Unilateral involvement only usually with minimal or no functional disability
2	Bilateral or midline involvement without impairment of balance
3	Bilateral disease: mild to moderate disability with impaired postural reflexes; physically independent
4	Severely disabling disease; still able to walk or stand unassisted
5	Confinement to bed or wheelchair unless aided

Voice Handicap Index (VHI)

The Voice Handicap Index (VHI) is a self-administered questionnaire to quantify the impact perceived by a subject affected by a vocal disorder of her/his own vocal function and the effects of the disorder on her/his life. This instrument was developed by Jacobson et al. (1997) and later, in 2007, it was validated in the Spanish context (Núñez-Batalla et al., 2007). It has both short (VHI-10) and long versions (VHI-30) with 10 and

30 items, respectively. In this study, the VHI-30 form was used in order to obtain as much information as possible about the participants' perceptions about their own voices. The VHI-30 contains 30 items organized into three subscales: physical emotional and functional subscales. Each question has five possible answering options: 0: without vocal involvement, 1: mild, 2: moderate, 3: severe and 4: serious. With regard to the psychometric properties of the instrument, the Cronbach's alpha coefficient was used to assess the reliability or homogeneity of the questions, resulting in high reliability (α= 0.93) (Núñez-Batalla et al., 2007). This coincides with the result we obtained in our study (α=0.94).

Acoustic variables

The analysis of the recorded voice signal provides an indirect measure of vibration pattern of the vocal folds, as well as the shape of the vocal tract and its changes over time (Benesty, Sondhi, & Huang, 2007). When attempting to detect and characterize pathological voices, the aim is to document their significant changes, which can be evidenced by the acoustic analysis of the signal (Elisei, 2012). In this work we will focus on the following acoustic parameters extracted from the recorded signal:

- **Voice intensity** (dB) is defined as the amplitude of the variation in sound pressure produced when the voice is transmitted in the air.
- The **shimmer** (dB) measures the variability of amplitude from cycle to cycle.
- The **fundamental frequency** (F_0) (Hz) represents the number of times the vocal cords open and close per second.
- The disturbance of the F_0 between two consecutive cycles is the **jitter**.
- The **NHR** is the relationship between harmonic energy and airborne noise energy at the output of the vocal cords.

- The **formant frequencies** refer to the resonant properties of the vocal tract. The formants directly depend on the configuration of the vocal tract during speech articulation and are characteristics of each phone (Benesty et al., 2007). Formants are called by integers and range from lower to higher frequency. Thus, F1 is the lowest frequency formant and is related to the mouth opening and F2 has a higher frequency and is related to the length of the anterior oral cavity (Quilis, 1981). In this study the formants were computed from the acoustic signals using the robust method proposed by Mustafa & Bruce, (2006).
- From the formants, we computed the **vowel space area (VSA)**, which is the area enclosed by the polygon defined by the five vowels, each one being a vertex of the polygon. Given the (□, □) coordinates (i.e. F2 and F1 values) of the vowels, the area of the polygon can be computed as follows:

$$= \frac{(□_□□_□ - □_□□_□) + (□_□□_□ - □_□□_□) + (□_□□_□ - □_□□_□) + (□_□□_□ - □_□□_□) + (□_□□_□ - □_□□_□)}{2}$$

Statistical analysis

Statistical analyses were performed using the SPSS software version 20.0 for Windows (SPSS Inc., Chicago, IL). First, descriptive analyses were carried out of the variables collected. Next, in order to choose the appropriate statistical tests to be analyzed, the normality, linearity and homoscedasticity assumptions of the data were verified. No asymmetry was observed within the normal range for any of the variables, nor was kurtosis within the normal range for any of the variables. The results obtained in the Kolmogorov-Smirnov test showed no normality for any of the variables. In addition, Levene's homoscedasticity tests showed no variance homogeneity for some of the variables ($p > 0.05$). Non-parametric statistical analyses were therefore carried out. Each

acoustic parameter computed from the recordings was compared between PD patients and the control group using the non-parametric test Mann-Whitney U test for independent samples. Spearman's Rho (ρ) coefficient was used to measure the degree of correlation between the scores of Hoehn and Yahr scale and HIV-30 scores, and between the scores of the Hoehn and Yahr scale and the VSA parameter. The significance level was 95%, with $p<0.05$ values considered statistically significant.

Results

Table 2 shows participants' main characteristics. The mean age of the PD patients was 76.50 ± 6.87 years, and the average age of the normal controls was 70.05 ± 4.43 years. There was no statistically significant difference between the two groups. In the PD patients group, the mean duration after diagnosis was 6.15 ± 2.76 years and the mean Hoehn and Yahr scale score was 2.5 ± 8.27, which reflects bilateral or midline involvement without impairment of balance to mild to moderate disability with impaired postural reflexes.

Table 2. Participants' main characteristics.

	Experimental group		Control group	
	Male	Female	Male	Female
N	12	8	12	8
Age	78.58 ± 6.52	73.38 ± 6.55	71.50 ± 3.92	67.88 ± 4.49
Time since diagnosed with EP	6.75 ± 2.30	5.25 ± 3.28		
Hoehn and Yahr	2.58 ± 0.79	2.38 ± 0.92		
VHI-30	36.75 ± 24.01	24.38 ± 12.88		

A scatter plot of the vowels recorded by the subjects in the experimental (Parkinson) and control groups when projected onto the plane defined by their first two formants is shown in Figure 1. As can be seen, vowels form different clusters in the formant space depending on their acoustic characteristics.

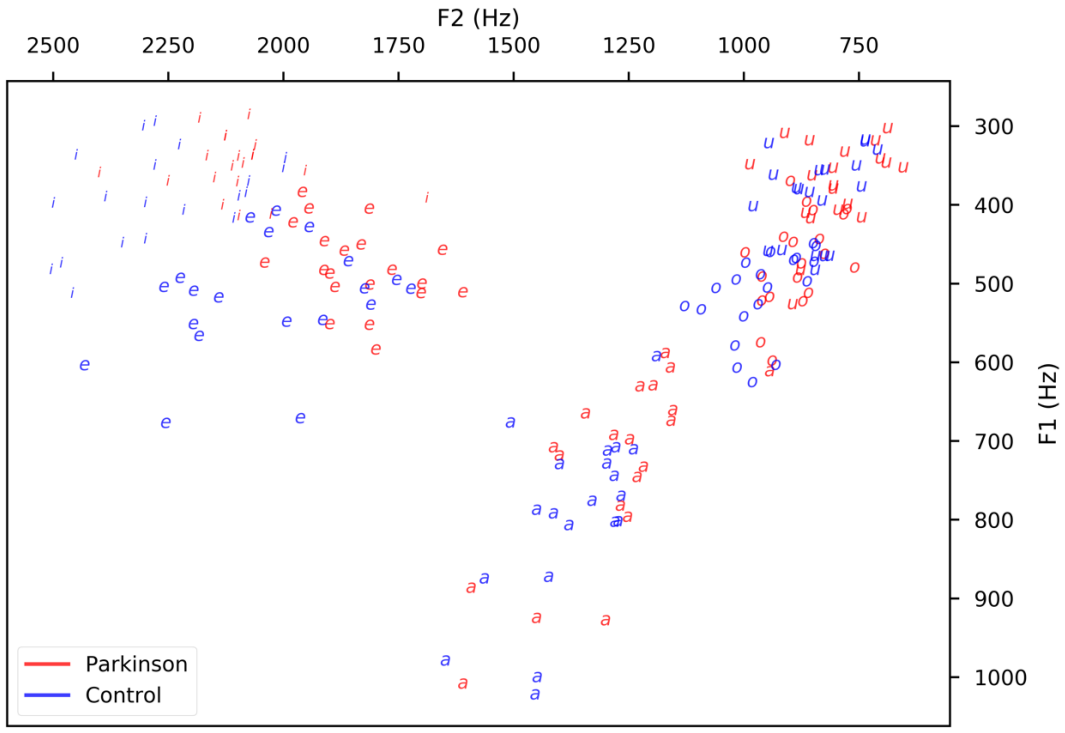

Figure 1. Scatter plot of the vowels for the PD and control groups.

Next, we studied whether significant differences exist between both groups when considering the formants as acoustic variables. As shown in Table 3, statistically significant differences were found between both groups in the F2 for men for /a/ and for /e/ and /i/ in the case of women. No significant differences were found for the F1 parameter. In all cases both the F1 and the F2 were significantly lower for the PD group compared to the healthy controls.

Table 3. Differences in the formant frequencies between the experimental and control groups

Parameter		Male			Female		
		Experimental group	Control group	P-value	Experimental group	Control group	P-value
F1	/a/	684.82 ± 69.23	738.56 ± 57.94	0.061	808.64 ± 143.52	877.92 ± 118.85	0.431
	/e/	459.44 ± 45.69	483.68 ± 50.74	0.175	506.88 ± 50.51	571.94 ± 72.83	0.066
	/i/	340.38 ± 35.84	369.16 ± 45.67	0.089	363.37 ± 35.00	419.96 ± 68.72	0.128
	/o/	467.28 ± 65.60	503.92 ± 50.05	0.194	477.33 ± 52.43	528.82 ± 58.65	0.066
	/u/	373.62 ± 61.85	376.64 ± 47.13	0.665	376.61 ± 53.91	412.54 ± 63.26	0.318
F2	/a/	1191.36 ± 89.80	1299.53 ± 68.99	0.002*	1418.07 ± 133.66	1480.75 ± 88.83	0.227
	/e/	1827.57 ± 140.94	1924.26 ± 131.65	0.141	1860.47 ± 49.85	2214.24 ± 128.65	0.001*
	/i/	2113.35 ± 164.08	2181.20 ± 137.13	0.507	2076.08 ± 61.79	2402.86 ± 109.49	0.001*
	/o/	873.21 ± 63.09	935.43 ± 65.66	0.053	896.48 ± 73.80	1002.01 ± 92.60	0.031
	/u/	796.66 ± 77.40	822.94 ± 76.44	0.341	811.04 ± 103.66	870.51 ± 77.81	0.495

An important parameter related to the formants is the VSA. The VSA has been previously used in other investigations to characterize speech motor control (Bang et al., 2013; Sabine Skodda, Grönheit, & Schlegel, 2012) and have been found to be related to the level of speech intelligibility (Liu, Tsao, & Kuhl, 2005; Turner, Tjaden, & Weismer, 1995). Here, we study whether this parameter is also affected in PD patients. Figure 2 shows a boxplot with the distribution of the vowel space area for the Parkinson and control groups. A Mann-Whitney U test revealed statistically significant differences between the vowel areas of PD patients (247867.35 ± 68934.36 Hz^2) and healthy controls (310516.64 ± 111523.19 Hz^2) (p=0.012). This is also visually apparent in Figure 1. The reduction in the vowel space area in the PD group can be attributed to vowel centralization as a consequence of a reduction in the amount of tongue movement after Parkinson's.

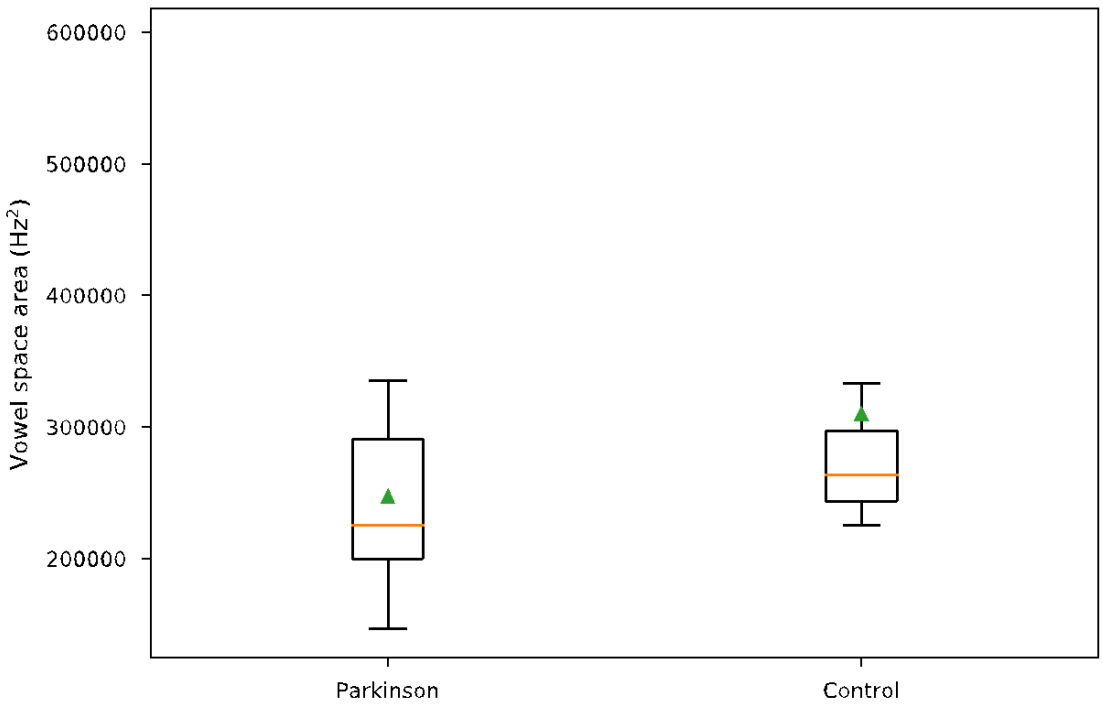

Figure 2. Comparison of the distributions of vowel space area for PD patients and healthy controls. Medians are represented with the horizontal yellow line and means are represented with a green triangle.

Table 4 shows the differences between the experimental and the control group for the rest of the acoustic parameters considered in this study. Statistically significant differences were found in the intensity of the /i/ for both men and women. For the F_0, significant differences were only found for the vowel /a/ for women. When *jitte*r was compared between the PD patients and the normal controls, the jitter value of the PD male patients for the vowel /i/ was significantly higher when compared with the healthy controls. On the contrary, the jitter value of the PD female patients for the vowel /i/ was significantly lower when compared with the healthy controls. In addition, the jitter value of the PD male patients for the vowel /u/ was significantly lower when compared with the healthy controls.

In the shimmer values, significant differences were found between the PD male patients and healthy controls for the vowel /u/, with PD patients obtaining higher values. Significant differences were also found between PD female patients and healthy control for the vowel /a/, with PD patients obtaining higher values. However, there was no statistically significant difference in the NHR between the experimental and control groups.

Table 4. *Intensity, F_0, Jitter, Shimmer and NHR for the experimental and the control groups*

Parameter		Male			Female		
		Experimental group	Control group	P-value	Experimental group	Control group	P-value
Intensity	/a/	81.87 ± 0.86	81.54 ± 0.89	0.644	81.21 ± 0.73	81.39 ± 0.58	0.875
	/e/	81.91 ± 0.56	81.62 ± 0.49	0.175	81.00 ± 0.66	81.11 ± 0.54	0.674
	/i/	82.09 ± 0.50	81.56 ± 0.43	0.009*	81.64 ± 0.67	80.95 ± 0.73	0.021*
	/o/	81.97 ± 0.68	81.72 ± 0.62	0.507	81.26 ± 0.40	81.39 ± 1.05	0.916
	/u/	82.33 ± 0.61	82.11 ± 0.57	0.419	81.47 ± 0.77	81.78 ± 0.67	0.462

F_0	/a/	141.68 ± 28.81	122.10 ± 16.80	0.073	196.28 ± 29.36	220.51 ± 15.58	0.045*
	/e/	143.19 ± 29.99	122.90 ± 15.57	0.119	195.65 ± 48.76	222.43 ± 21.30	0.059
	/i/	145.80 ± 28.70	130.38 ± 19.49	0.225	189.65 ± 30.57	233.01 ± 27.33	0.141
	/o/	141.65 ± 29.44	129.29 ± 20.57	0.419	197.54 ± 30.57	228.43 ± 20.58	0.074
	/u/	146.23 ± 27.61	134.11 ± 19.89	0.225	203.20 ± 31.35	233.77 ± 28.31	0.074
Jitter	/a/	0.26 ± 0.14	0.19 ± 0.07	0.183	0.19 ± 0.76	0.15 ± 0.05	0.171
	/e/	0.18 ± 0.06	0.16 ± 0.06	0.401	0.16 ± 0.12	0.20 ± 0.09	0.082
	/i/	0.20 ± 0.06	0.14 ± 0.06	0.034*	0.12 ± 0.06	0.20 ± 0.08	0.045*
	/o/	0.20 ± 0.08	0.16 ± 0.10	0.370	0.14 ± 0.07	0.19 ± 0.05	0.140
	/u/	0.03 ± 0.26	0.13 ± 0.06	0.009*	0.23 ± 0.18	0.15 ± 0.06	0.429
Shimmer	/a/	5.61 ± 2.46	4.58 ± 1.37	0.525	4.02 ± 0.65	2.87 ± 0.56	0.006*
	/e/	3.79 ± 1.36	4.28 ± 1.00	0.184	3.12 ± 1.31	2.75 ± 0.87	0.529
	/i/	3.39 ± 1.36	3.17 ± 0.98	0.908	2.60 ± 1.04	2.55 ± 1.31	0.752
	/o/	4.84 ± 2.85	3.88 ± 1.70	0.453	1.75 ± 0.87	2.48 ± 0.63	0.066
	/u/	5.73 ± 3.14	2.74 ± 1.25	0.005*	3.19 ± 1.22	1.91 ± 0.78	0.074
NHR	/a/	0.04 ± 0.03	0.02 ± 0.02	0.093	0.02 ± 0.01	0.01 ± 0.01	0.101
	/e/	0.02 ± 0.02	0.02 ± 0.01	0.885	0.01 ± 0.01	0.02 ± 0.02	0.205
	/i/	0.02 ± 0.02	0.02 ± 0.01	0.354	0.01 ± 0.01	0.02 ± 0.01	0.072
	/o/	0.02 ± 0.02	0.01 ± 0.01	0.156	0.01 ± 0.00	0.01 ± 0.00	0.366
	/u/	0.03 ± 0.02	0.01 ± 0.01	0.060	0.01 ± 0.02	0.00 ± 0.00	0.109

Next, we studied whether the acoustic parameters and the VHI-30 scores obtained by the subjects were related. No significant correlations were found between the acoustic parameters measured in this study and the patient's self-perceived voice quality (p>.05). Similarly, no association was found between the scores on the VHI-30 and the Hoehn and Yahr score, (ρ=0.407; p=0.075), between the score on the VHI-30 and participants' age

(ρ =0.21; $p>.05$), nor between the score on the VHI-30 and the time since participants were diagnosed with PD (ρ =-0.08; $p>.05$). Finally, no significant correlation was found between the scores on the Hoehn and Yahr scale and the VSA (ρ=- 0.21; p=0.38).

Discussion

The aim of the current study was to assess the quality of the voice of patients with PD and hypokinetic dysarthria using objective metrics computed from voice recordings. During the course of the disease, PD patients normally develop hypokinetic dysarthria, a speech disorder which affects their voices and, hence, has a direct impact on their daily lives. The effects of the dysarthria on the patient's voice are noticeable when voice is either perceptually or acoustically analyzed.

Our acoustic analysis showed a significant difference in the voice intensity between the control group and the experimental group, for both men and women, in the vowel /i/. This difference might be related to /i/ being the most closed and anterior vowel so it requires great precision in order to be articulated. This articulatory precision is diminished in PD patients due to dysarthria (Rusz et al., 2011).

In relation to the F_0 parameter, statistically significant differences were found between the women in the control and the experimental groups for /a/, but no significant differences were found for the men. Other studies (De Keyser et al., 2016; Jaywant & Pell, 2010; Rodrigues das Graças et al., 2012) reported no significant differences in the F_0 even for women. The F_0 is determined by the frequency to which the vocal folds vibrate. In patients with PD, the rigidity of the laryngeal muscle alters the physical properties of the vocal folds and, hence, the F_0 (Tanaka et al., 2011).

Regarding the jitter, statistically significant differences were found in both genders for the vowel /i/. This is consistent with findings from other studies (Bang et al.,

2013; Rodrigues das Graças et al., 2012; Tanaka et al., 2011). For men, significant differences were also found for /u/. Individuals with PD have involuntary motor activity affecting the constriction pattern of the laryngeal muscles even at vocal rest. This involuntary motor activity may be related to the difficulty of controlling vocal fold vibration and, hence, the changes in the jitter (Rodrigues das Graças et al., 2012).

Other studies from the literature reported no significant differences between groups in the shimmer parameter (Bang et al., 2013; Jaywant & Pell, 2010; Rodrigues das Graças et al., 2012; Skodda et al., 2013). This is not our case, where significant differences were found in the /u/ for men and in the /a/ for women. The differences between our work and other previous studies may be related to the number of subjects and the acoustic analysis program used.

In common with other studies (Bang et al., 2013; Jaywant & Pell, 2010; Rodrigues das Graças et al., 2012; Skodda et al., 2013), we did not find any statistically significant differences in any of the five vowels for the NHR parameter.

An important symptom of most types of dysarthria is the reduced amplitude of the articulator movements (Bang et al., 2013). As a consequence, the tongue movements during articulation are altered, which directly affects the resonance properties of the vocal tract (i.e. the formants) and, hence, speech intelligibility. In common with other recent studies (Bang et al., 2013; Skodda et al., 2013) we also found significant differences between both groups for the isolated formants and the VSA These changes are likely produced by the dysarthria and are known to ameliorated following voice treatment (Sapir, 2014).

We attempted to establish a relationship between the results of the VHI-30 and the acoustic parameters, but we found no statistically significant differences. The lack of relationship might be due to the fact that individuals suffering from PD might not be not

aware that their voice is weak, nor that it is progressively weakening if they do not make a constant effort during the utterance (Bermúdez de Alvear & Martínez Arquero, 2013). It is also possible that this lack of association could be due to the fact that the PD patients who took part in this study obtained relatively low scores on the Hoehn and Yahr scale, were all treated with antiparkinsonian medications, were in the ON phase when the recordings were performed and received speech therapy. Also the sample size of this study was small. As PD patients are not aware that their voice is changing until a later stage of the disease (Wight & Miller, 2015), futures studies aiming at studying the relationship between PD patients' perception of the quality of their voice and acoustic parameters should include larger samples and PD patients with stages 3 and 4 of Hoehn and Yahr scale and patients who are on the OFF phase.

Conclusions

The current study showed that people with PD have greater vocal changes compared to healthy individuals. Acoustic analysis shows differences between the experimental group and the control group for some of the vocalizations studied. This demonstrates the effect of PD on the voice of these patients and the importance of speech and language therapy in this group of subjects.

Regarding study limitations, the sample of patients is limited, since it was difficult in the limited time of the study to obtain a larger sample that meets all the requirements. Secondly, it would be interesting to perform the study with subjects who have not received any voice therapy. In this case, the differences between the control group and the Parkinson's group may be greater.

Despite these limitations, it was shown that differences do exist between the voice of patients with PD and hypokinetic dysarthria and healthy patients. Furthermore, no significant correlations were found between the patient's self-perceived voice quality

and the acoustic parameters computed from the voice recordings. In future and within the scope of speech therapy, it would be interesting to conduct a longitudinal study of the voice in subjects with Parkinson's who have not received any vocal therapy to ascertain how their voices change over time. In addition, in order to analyze the aspects that most benefit from the rehabilitation PD patients, it would be interesting to perform an objective and perceptual study of the voice of these patients before and after performing the speech therapy.

References

Aarsland, D., Påhlhagen, S., Ballard, C. G., Ehrt, U., & Svenningsson, P. (2012). Depression in Parkinson disease—epidemiology, mechanisms and management. *Nature Reviews Neurology*, *8*(1), 35.

Bang, Y.-I., Min, K., Sohn, Y. H., & Cho, S.-R. (2013). Acoustic characteristics of vowel sounds in patients with Parkinson disease. *NeuroRehabilitation*, *32*(3), 649–654.

Benesty, J., Sondhi, M. M., & Huang, Y. (2007). *Springer handbook of speech processing*. Springer.

Bermúdez de Alvear, R. M., & Martínez Arquero, A. G. (2013). Estrategias para potenciar el aprendizaje motor en el tratamiento vocal de las enfermedades neurodegenerativas. *Revista de Logopedia, Foniatría y Audiología*, *33*(1), 13–24.

De Keyser, K., Santens, P., Bockstael, A., Botteldooren, D., Talsma, D., De Vos, S., … De Letter, M. (2016). The relationship between speech production and speech perception deficits in Parkinson's disease. *Journal of Speech, Language, and Hearing Research*, *59*(5), 915–931.

Delgado-Hernández, J. (2017). Estudio piloto sobre los valores acústicos de las vocales

en español como indicadores de la gravedad de la disartria. *Revista de Neurología, 64*(3), 105-111.

Duffy, J. R. (2013). *Motor Speech disorders-E-Book: Substrates, differential diagnosis, and management*. Elsevier Health Sciences.

Elisei, N. G. (2012). Análisis acústico de la voz normal y patológica utilizando dos sistemas diferentes: ANAGRAF y PRAAT. *Interdisciplinaria, 29*(2), 339-357.

Goetz, C. G., Poewe, W., Rascol, O., Sampaio, C., Stebbins, G. T., Counsell, C., … others. (2004). Movement Disorder Society Task Force report on the Hoehn and Yahr staging scale: status and recommendations the Movement Disorder Society Task Force on rating scales for Parkinson's disease. *Movement Disorders*, *19*(9), 1020–1028.

Hirsch, L., Jette, N., Frolkis, A., Steeves, T., & Pringsheim, T. (2016). The incidence of Parkinson's disease: a systematic review and meta-analysis. *Neuroepidemiology*, *46*(4), 292–300.

Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: onset, progression, and mortality. *Neurology*, *17*(5), 427–427.

Jacobson, B. H., Johnson, A., Grywalski, C., Silbergleit, A., Jacobson, G., Benninger, M. S., & Newman, C. W. (1997). The voice handicap index (VHI) development and validation. *American Journal of Speech-Language Pathology*, *6*(3), 66–70.

Jaywant, A., & Pell, M. D. (2010). Listener impressions of speakers with Parkinson's disease. *Journal of the International Neuropsychological Society*, *16*(1), 49–57.

Kim, H., Hasegawa-Johnson, M., & Perlman, A. (2011). Vowel contrast and speech intelligibility in dysarthria. *Folia Phoniatrica et Logopaedica*, *63*(4), 187-194.

Landsford, K. L., & Liss, J.M. (2014). Vowel acoustic in dysarthria:speech disorder diagnosis and classification. *Journal of Speech, Language, and Hearing Research, 57*(1), 57-67.

Leiknes, I., Tysnes, O.-B., Aarsland, D., & Larsen, J. (2010). Caregiver distress associated with neuropsychiatric problems in patients with early Parkinson's disease: the Norwegian ParkWest study. *Acta Neurologica Scandinavica, 122*(6), 418–424.

Liu, H. M., Tsao, F. M., & Kuhl, P. K. (2005). The effect of reduced vowel working space on speech intelligibility in Mandarin-speaking young adults with cerebral palsy. *Journal of the Acoustical Society of America, 117*(6), 3879-3889.

Mate, M. A., Cobeta, I., Jiménez-Jiménez, F. J., & Figueiras, R. (2012). Digital voice analysis in patients with advanced Parkinson's disease undergoing deep brain stimulation therapy. Journal of Voice, 26(4), 496-501.

McLaughlin, D., Hasson, F., Kernohan, W. G., Waldron, M., McLaughlin, M., Cochrane, B., & Chambers, H. (2011). Living and coping with Parkinson's disease: perceptions of informal carers. *Palliative Medicine, 25*(2), 177–182.

McRae, P. A., Tjaden, K., & Schoonings, B. (2002). Acoustic and perceptual consequences of articulatory rate change in Parkinson's disease. *Journal of Speech, Language, and Hearing Research, 45*(1), 35-50.

Midi, I., Dogan, M., Koseoglu, M., Can, G., Sehitoglu, M., & Gunal, D. (2008). Voice abnormalities and their relation with motor dysfunction in Parkinson's disease. *Acta Neurologica Scandinavica, 117*(1), 26–34.

Miller, N., Allcock, L., Jones, D., Noble, E., Hildreth, A. J., & Burn, D. J. (2007).

Prevalence and pattern of perceived intelligibility changes in Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *78*(11), 1188–1190.

Mustafa, K., & Bruce, I. C. (2006). Robust formant tracking for continuous speech with speaker variability. *IEEE Transactions on Audio, Speech, and Language Processing*, *14*(2), 435–444. https://doi.org/10.1109/TSA.2005.855840

Núñez-Batalla, F., Corte-Santos, P., Señaris-González, B., Llorente-Pendás, J. L., Górriz-Gil, C., & Suárez-Nieto, C. (2007). Adaptación y validación del índice de incapacidad vocal (VHI-30) y su versión abreviada (VHI-10) al español. *Acta Otorrinolaringológica Española*, *58*(9), 386–392.

Oguz, H., Tunc, T., Safak, M. A., Inan, L., Kargin, S., & Demirci, M. (2006). Objective voice changes in nondysphonic Parkinson's disease patients. *Journal of Otolaryngology*, *35*(5), 349-354.

Perez-Lloret, S., Nègre-Pagès, L., Ojero-Senard, A., Damier, P., Destée, A., Tison, F., … Group, C. S. (2012). Oro-buccal symptoms (dysphagia, dysarthria, and sialorrhea) in patients with Parkinson's disease: preliminary analysis from the French COPARK cohort. *European Journal of Neurology*, *19*(1), 28–37.

Pringsheim, T., Jette, N., Frolkis, A., & Steeves, T. D. (2014). The prevalence of Parkinson's disease: A systematic review and meta-analysis. *Movement Disorders*, *29*(13), 1583–1590.

Quilis, A. (1981). *Fonética acústica de la lengua española* (Vol. 49). Gredos Madrid.

Rodrigues das Graças, R., Côrtes Gama, A. C., Costa Cardoso, F. E., Pereira Lopes, B., & Barreto Bassi, I. (2012). Objective and subjective analysis of women's voice with idiopathic Parkinson's disease. *Arquivos de Neuro-Psiquiatria*, *70*(7), 492–496.

Rusz, J., Čmejla, R., Růžičková, H., Klempíř, J., Majerová, V., Picmausová, J., … Růžička, E. (2013). Evaluation of speech impairment in early stages of Parkinson's disease: a prospective study with the role of pharmacotherapy. *Journal of Neural Transmission, 120*(2), 319–329.

Rusz, J., Čmejla, R., Růžičková, H., & Růžička, E. (2011). Quantitative acoustic measurements for characterization of speech and voice disorders in early untreated Parkinson's disease. *The Journal of the Acoustical Society of America, 129*(1), 350–367.

Sapir, S. (2014). Multiple factors are involved in the dysarthria associated with Parkinson's disease: A review with implications for clinical practice and research. *Journal of Speech, Language, and Hearing Research, 57*(4), 1330–1343.

Sapir, S., Ramig, L., Spielman, J., & Fox, C. (2010). Formant centralization ratio (FCR) as an acoustic index of dysarthric vowel articulation: comparison with vowel space area in Parkinson disease and healthy aging. *Journal of Speech, Language, and Hearing Research, 53*(1), 114-125.

Skodda, S, Grönheit, W., Mancinelli, N., & Schlegel, U. (2013). Progression of voice and speech impairment in the course of Parkinson's disease: a longitudinal study. *Parkinson's Disease, 2013*.

Skodda, Sabine, Grönheit, W., & Schlegel, U. (2012). Impairment of vowel articulation as a possible marker of disease progression in Parkinson's disease. *PloS One, 7*(2), e32132.

Skodda, Sabine, Rinsche, H., & Schlegel, U. (2009). Progression of dysprosody in Parkinson's disease over time—a longitudinal study. *Movement Disorders: Official*

Journal of the Movement Disorder Society, 24(5), 716–722.

Sveinbjornsdottir, S. (2016). The clinical symptoms of Parkinson's disease. *Journal of Neurochemistry*, *139*, 318–324.

Tanaka, Y., Nishio, M., & Niimi, S. (2011). Vocal acoustic characteristics of patients with Parkinson's disease. *Folia Phoniatrica et Logopaedica, 63*(5), 223–230.

Turner, G. S., Tjaden, K., & Weismer, G. (1995). The influence of speaking rate on vowel space and speech intelligibility for individuals with amyotrophic lateral sclerosis. *Journal of Speech, Language, and Hearing Research, 38*(5), 1001-1013.

Tysnes, O.-B., & Storstein, A. (2017). Epidemiology of Parkinson's disease. *Journal of Neural Transmission*, *124*(8), 901–905.

Watts, C. R. (2016). A retrospective study of long-term treatment outcomes for reduced vocal intensity in hypokinetic dysarthria. *BMC Ear, Nose and Throat Disorders, 16*(1), 2.

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), 1-18.

Wight, S., & Miller, N. (2015). Lee Silverman Voice Treatment for people with Parkinson's: audit of outcomes in a routine clinic. *International Journal of Language & Communication Disorders*, *50*(2), 215–225.

Zarzur, A. P., Duprat, A. C., Shinzato, G., & Eckley, C. A. (2007). Laryngeal electromyography in adults with Parkinson's disease and voice complaints. *The Laryngoscope*, *117*(5), 831–834.