



**HAL**  
open science

## Do Acoustic Characteristics of Dysarthria in People With Parkinson's Disease Differ Across Languages?

Serge Pinto, Rita Cardoso, Cyril Atkinson-Clement, Isabel Guimarães, Jasmin Sadat, Helena Santos, Céline Mercier, Joana Carvalho, Marie-Charlotte Cuartero, Pedro Guedes de Oliveira, et al.

### ► To cite this version:

Serge Pinto, Rita Cardoso, Cyril Atkinson-Clement, Isabel Guimarães, Jasmin Sadat, et al.. Do Acoustic Characteristics of Dysarthria in People With Parkinson's Disease Differ Across Languages?. Journal of Speech, Language, and Hearing Research, 2024, pp.1-20. 10.1044/2024\_JSLHR-23-00525 . hal-04608343

**HAL Id: hal-04608343**

**<https://hal.science/hal-04608343v1>**

Submitted on 18 Dec 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

1 **Do acoustic characteristics of dysarthria in people with Parkinson's disease differ across languages?**

2 Serge Pinto, PhD,<sup>1</sup>Rita Cardoso, SLP, MSc,<sup>2,3</sup> Cyril Atkinson-Clement, MPsy, PhD,<sup>1,4</sup> Isabel Guimarães,  
3 SLP, PhD,<sup>3,5</sup> Jasmin Sadat, PhD,<sup>1</sup>Helena Santos, SLP, MSc,<sup>2</sup>Céline Mercier, SLP,<sup>1,6</sup> Joana Carvalho, SLP,  
4 MSc,<sup>2</sup> Marie-Charlotte Cuartero, MPsy, PhD,<sup>1</sup>Pedro Oliveira, PhD,<sup>7</sup> Pauline Welby, PhD,<sup>1</sup>Sónia Frota,  
5 PhD,<sup>8</sup> Emilie Cavazzini, MPsy,<sup>1</sup>Marina Vigário, PhD,<sup>8</sup> Alban Letanneux, PhD,<sup>9</sup> Marisa Cruz, PhD,<sup>8</sup>  
6 Coralie Brulefert, SLP,<sup>1</sup>Morgane Desmoulin, SLP,<sup>1</sup> Isabel Pavão Martins, MD, PhD,<sup>10</sup> Rui Rothe-  
7 Neves, PhD,<sup>11</sup> François Viallet, MD, PhD,<sup>1,6</sup> Joaquim J. Ferreira, MD, PhD,<sup>2,3</sup>

8 <sup>1</sup> Aix Marseille Univ, CNRS, LPL, Aix-en-Provence, France

9 <sup>2</sup> CNS - Campus Neurológico Sénior, Torres Vedras, Portugal

10 <sup>3</sup> Instituto de Medicina Molecular (IMM), Faculdade de Medicina, University of Lisbon, Portugal

11 <sup>4</sup> Precision Imaging Beacon, School of Medicine, University of Nottingham, UK

12 <sup>5</sup> Alcoitão Health School of Sciences, Speech Therapy Department, Alcabideche, Portugal

13 <sup>6</sup> Neurology Department, Centre Hospitalier Intercommunal du Pays d'Aix, Aix-en-Provence, France

14 <sup>7</sup> Université Jean Moulin, Lyon 3, France

15 <sup>8</sup> Center of Linguistics, School of Arts and Humanities, University of Lisbon, Portugal

16 <sup>9</sup> ESPE Université Paris-Est Créteil, Laboratoire CHArt-UPEC (EA 4004), Bonneuil-sur-Marne, France

17 <sup>10</sup> Language Research Laboratory, Neurology Department, University of Lisbon, Portugal

18 <sup>11</sup> Laboratório de Fonética, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, Brasil

19 **Corresponding author:**

20 Serge Pinto, Ph.D.

21 Laboratoire Parole et Langage (LPL), UMR 7309 - CNRS / Aix-Marseille Université

22 5 avenue Pasteur, 13100 Aix-en-Provence, France

23 +33 4 13 55 36 23 serge.pinto@univ-amu.fr

24 **Keywords:** Parkinson's disease; Dysarthria; Cross-language; Medical treatment; Portuguese; French

25 **Abstract**

26 **Purpose:** Cross-language studies suggest more similarities than differences in how dysarthria affects  
27 the speech of people with Parkinson’s disease (PwPD) who speak different languages. In this study,  
28 we aimed to identify the relative contribution of acoustic variables to distinguish PwPD from controls  
29 who spoke varieties of two Romance languages, French and Portuguese.

30 **Method:** This bi-national, cross-sectional, and case-controlled study included 129 PwPD and 124  
31 healthy controls who spoke French or Portuguese. All participants underwent the same clinical  
32 examinations, voice/speech recordings, and self-assessment questionnaires. PwPD were evaluated  
33 *off* and *on* optimal medication. Inferential analyses included Disease (controls vs. PwPD) and  
34 Language (French vs. Portuguese) as factors, and random decision forest algorithms identified  
35 relevant acoustic variables able to distinguish participants: i) by language (French vs. Portuguese) and  
36 ii) by clinical status (PwPD *on* and *off* medication vs. controls).

37 **Results:** French-speaking and Portuguese-speaking individuals were distinguished from each other  
38 with over 90% accuracy by five acoustic variables (the mean F0 and the shimmer of the sustained  
39 vowel /a/ production, the oral diadochokinesis performance index, the relative SPL and the relative  
40 SPL\_SD of the text reading). A distinct set of parameters discriminated between controls and PwPD:  
41 for men, maximum phonation time and the oral diadochokinesis speech proportion were the most  
42 significant variables; for women, variables calculated from the oral diadochokinesis were the most  
43 discriminative.

44 **Conclusions:** Acoustic variables related to phonation and voice quality distinguished between  
45 speakers of the two languages. Variables related to pneumophonic coordination and articulation rate  
46 were the more effective in distinguishing PwPD from controls. Thus, our research findings support  
47 that respiration and diadochokinesis tasks appear to be the most appropriate to pinpoint signs of

48 dysarthria, which are largely homogeneous and language-universal. In contrast, identifying language-  
49 specific variables with the speech tasks and acoustic variables studied was less conclusive.

## 50 **Introduction**

51 People with Parkinson's disease (PwPD) face several impairments of voice and speech, referred to as  
52 hypokinetic dysarthria (Darley et al., 1969a, 1969b). The key features of speech in PwPD are  
53 monopitch, reduced stress, monoloudness, imprecise consonants, inappropriate silences, short  
54 rushes of speech, harsh and breathy voice, low pitch, and variable rate (Darley et al., 1969a, 1969b).  
55 An additional and potential marker of dysarthria in PwPD is reduced loudness or hypophonia (Becker  
56 et al., 2002; Canter, 1963; Fox & Ramig, 1997; Hlavnička et al., 2017; Ho et al., 1999; Liotti et al.,  
57 2003; Rusz et al., 2013).

58 Dysarthria is a complex symptom resulting from multiple factors (for a review, see Sapir, 2014). The  
59 particular language a person speaks is a key variable that may influence how listeners perceive  
60 dysarthric speech. Much of the literature on dysarthria in PD focuses on English or a few other  
61 languages, leading to a predominant English-centered perspective in the field and leaving aside  
62 thousands of other world languages, which is an issue in various disciplines (García et al., 2023).  
63 Studies examining the impact of speech difficulties from a cross-language perspective are increasing  
64 in number, providing arguments in favor of language-universal and language-specific aspects of  
65 dysarthric speech (Levy & Moya-Galé, 2023; Moya-Galé et al., 2023). For example, as it is mentioned  
66 as a critical component of communication deficits in people with motor speech disorders, speech  
67 rhythm could affect communication as a language-specific feature (Liss et al., 2013). So far,  
68 researchers have discovered more similarities than differences in how dysarthria affects the speech  
69 and/or intelligibility of PwPD in different languages. For instance, similarities were found between  
70 dysarthric English and Chinese speakers with cerebral palsy or Parkinson's disease (Whitehill, 2010).  
71 Dysarthria in Cantonese-speaking PwPD seems also perceptually very similar to that of English and  
72 Japanese-speaking PwPD (Whitehill et al., 2003). These examples support language-universal aspects  
73 of dysarthria in PwPD. Recent studies have developed automatic acoustic approaches to determine  
74 common variables for patient identification across different languages (Favaro et al., 2023; Moreno-

75 Acevedo et al., 2023; Scimeca et al., 2023). Studies have not found language-specific differences  
76 between controls and PwPD in a broad range of acoustic parameters in Czech, American English,  
77 German, French, and Italian – languages that were found to differ in several acoustic parameters.  
78 Classic dysfunctions of PD voice and speech (monopitch, prolonged pauses, and imprecise  
79 consonants) were thus automatically detected across the six languages (Rusz et al., 2021). This aligns  
80 with previous findings for Spanish, German, and Czech (Orozco-Arroyave et al., 2016) when running  
81 an automatic segmentation of utterances in isolated words, diadochokinesis, sentences, or read  
82 texts. Following the same type of automatic speech analysis, deficits in morphological processing  
83 were also similar in the same set of languages studied (Eyigoz et al., 2020). Perceptual studies have  
84 also provided arguments for language-universal aspects of dysarthria in PwPD: raters can  
85 discriminate speech between controls and PwPD, independently of the language spoken by the  
86 raters, *i.e.*, Dutch or non-Dutch listeners (Verkhodanova, Coler, Jonkers, Timmermans, et al., 2022).  
87 This classification capacity can be interpreted as non-native listeners perceptually focusing on  
88 “speech rate, presence of phonation deficiency reflected by maximum phonation time measurement,  
89 and centralization of the vowels” (Verkhodanova, Coler, Jonkers, Timmermans, et al., 2022, page 16),  
90 rather than the content of the message (Verkhodanova, Coler, Jonkers, & Lowie, 2022).

91 Alongside these similarities, García et al. reported that linguistic idiosyncrasies have also been found  
92 in speech in PwPD (García et al., 2023). Many possible reasons point to language-specific differences  
93 in the assessment and impact of dysarthria in PwPD, all of which rely on particular properties of a  
94 given language (Miller & Lowit, 2014). For example, differences between Cantonese and Mandarin  
95 speakers may highlight possible language-specific aspects of dysarthria, which could be attributed to  
96 the distinct phonologies of the two languages (Whitehill, 2010). A study comparing American English  
97 and Korean-speaking PwPD indicated that while acoustic vowel space was the main contributor to  
98 speech intelligibility, two additional variables (voice onset time and articulation rate) also  
99 contributed to intelligibility in Korean (Kim & Choi, 2017). As it comes to a higher cognitive level,  
100 word processing in PD was shown to be impaired for action verbs but not for concrete nouns in

101 French (Boulenger et al., 2008); a selective action-verb deficit was noted in Spanish speakers (García  
102 et al., 2018) but not in speakers of Danish (Møller et al., 2023). This was explained primarily by  
103 differences in vocabulary and syntax between the two languages and in linguistic context (García &  
104 Ibáñez, 2023).

105 In the FraLusoPark project (Pinto et al., 2016), a large set of clinical, patient-reported, and acoustic  
106 measures was integrated into the construction of a database that included speech productions from  
107 PwPD speaking varieties of two Romance languages, Metropolitan French (from France) and European  
108 Portuguese (from Portugal). French and Portuguese share certain vocabulary and grammar features,  
109 which might reduce the relevance of a cross-linguistic comparison. However, they differ substantially  
110 in phonetics and phonology, making the comparison between the two languages interesting in  
111 searching for acoustic variables more sensitive to PD in one language than in the other.

112 French is usually described as a language with fixed stress as it has a primary stress regularly assigned  
113 to the final full syllable of the last lexical item of a stress group. A secondary stress, which is non-final  
114 and optional, is more generally assigned to the first syllable of a content word (Di Cristo, 1998).  
115 Implementing these stresses implies pitch prominence and primary stress, but not secondary stress, is  
116 also manifested by temporal cues. Thus, French intonation is generally characterized by a fundamental  
117 frequency (F0) rise on the last syllable of a phrase that is not utterance-final; an optional early, or initial,  
118 rise may occur somewhere before the late, or final, rise (Welby, 2006). Authors usually agree that there  
119 is an early rise and a late rise, although some disagreement appears to be related to the structure of  
120 such rises. A prosodic grouping higher than the word is often reported (Welby, 2006).

121 Unlike French, Portuguese is a language with variable stress. Lexical stress may fall within the last three  
122 syllables of a word, and the stressed syllable can distinguish between words as, *e.g.*, in “*número*”  
123 *number* versus “*numero*” / *number* (Mateus & de Andrade, 2002). The correlates of stress in  
124 Portuguese combine prosodic with vowel quality cues. The main prosodic correlates are temporal cues,  
125 not pitch prominence (Delgado-Martins, 1986). Primary stress is signaled by vowel quality cues: unlike

126 stressed vowels, unstressed vowels are reduced (Mateus & de Andrade, 2002). Given that pitch is not  
127 an acoustic correlate of stress in that language, Portuguese intonation differs substantially from French  
128 intonation. In Portuguese, intonational pitch movements signal the most prominent syllable in the  
129 utterance, which is typically in the utterance-final word (Frota, 2014).

130 Compared to French, Portuguese is a language with a rather lax articulation and presents various  
131 phonetic modifications, *e.g.*, plosives may be spirantized, and the articulation of unstressed vowels is  
132 often undershot. Moreover, unlike in French, the syllable cannot be taken as the timing unit in  
133 Portuguese since phonetic syllables may be blended through the collapse of weak vowels in connected  
134 speech. Indeed, the rhythm of Portuguese has been described to be mixed and not syllable-based as  
135 in French (Frota & Vigário, 2001). One could argue that Portuguese-speaking PwPD are trained to  
136 preserve word stress, because it is important to word meaning. In contrast, French-speaking PwPD  
137 would have no reason to preserve this dimension since stress cannot lead words to change meaning  
138 in French. Furthermore, intonational patterns in French are more phrase-based, marking prosodic  
139 groupings higher than the word, whereas in Portuguese they delimit the utterance. If PwPD preserve  
140 these contrasting patterns, then sequences of melodic rises and falls would be more common in French  
141 than in Portuguese. Alternatively, an equally impaired melodic curve across PwPD could be defined by  
142 the speech characteristic of monopitch in PD.

143 The aims of the current study were, on the one hand, to identify relevant acoustic variables that would  
144 distinguish French-speaking versus Portuguese-speaking individuals, while controlling for gender  
145 (men/women), group (controls/PwPD), and medication state (on/off). On the other hand, we aim to  
146 identify the acoustic variables that distinguish controls from PwPD, with analyses performed by  
147 gender, language, and medication states. For this purpose, we used a classificatory analysis to identify  
148 the separate contribution of each acoustic variable when distinguishing groups with the highest  
149 accuracy. Because of the above-mentioned language-related specificities, we expected some acoustic  
150 variables to differ between French-speaking and Portuguese-speaking controls.



151 As mentioned previously, we established for PwPD two alternative a priori hypotheses based upon two  
152 different perspectives (Pinto et al., 2017): (i) according to a disease-based account, these differences  
153 could disappear in PwPD since dysarthric signs could be language-universal, constant and  
154 homogeneous; (ii) from a more language-specific account, these differences could be exacerbated in  
155 one specific language due to articulatory specificities that could be more vulnerable in one language  
156 as compared to the other. In the latter case, we would expect different impacts of dysarthria in PwPD's  
157 communication according to their language, and we hypothesized that this would be reflected in our  
158 patient cohorts in terms of intelligibility and the psychosocial impact of dysarthria.

## 159 **Method**

### 160 ***Study design***

161 FraLusoPark is a bi-national, cross-sectional, and case-controlled study with PwPD and healthy  
162 controls speaking varieties of two Romance languages, namely Metropolitan French (from France)  
163 and European Portuguese (from Portugal). The reported study protocol (Pinto et al., 2016) was  
164 approved by the local ethics committees (*France: Comité de Protection des Personnes, Sud*  
165 *Méditerranée 1; Portugal: Ethics Committee of the Lisbon Academic Medical Centre*) and registered  
166 under the reference NCT02753192 on <https://clinicaltrials.gov/>. The study was conducted following  
167 the ethical standards of the Declaration of Helsinki (World Medical Association Declaration of  
168 Helsinki, 2013). PwPD and controls were included in the study after providing their written informed  
169 consent.

### 170 ***Participants***

171 PwPD were recruited either in France (N=64; Neurology Department, Centre Hospitalier du Pays  
172 d'Aix, Aix-en-Provence, France) or in Portugal (n=84; Movement Disorders Unit, Hospital de Santa  
173 Maria, Lisbon, and Campus Neurológico Sénior [CNS], Torres Vedras, Portugal). PwPD met the UK  
174 Parkinson's Disease Brain Bank Criteria (Gibb & Lees, 1988) for diagnosing idiopathic PD. All

175 participants were right-handed and native speakers of French or Portuguese (French-Portuguese  
176 bilinguals were excluded from the study). Two groups of healthy volunteers (N=68 in France, n=74 in  
177 Portugal), age- and gender-matched with the PwPD, were also included in the study as controls.  
178 Exclusion criteria for participants were the following: illiteracy; non-native French/Portuguese  
179 speakers or French-Portuguese bilinguals; participants under tutorship or guardianship, or any other  
180 administrative or legal dependence; consent withdrawn; cognitive deficits, severe depression,  
181 dementia, psychosis (including medication-induced) or behavioral, neurological, medical, or  
182 psychological disorders that could have interfered with evaluations (clinically assessed by the  
183 neurologists during participant screening). For PwPD, additional exclusion criteria included non-  
184 idiopathic PD, deep brain stimulation, and severe motor impairment impeding participation in the  
185 study. To gauge speech changes at various stages of the disease, the PwPD were initially recruited  
186 (Pinto et al., 2016) to reflect a large spectrum of disease severity according to disease duration and  
187 the modified Hoehn & Yahr stage (Goetz et al., 2004). Since the primary aim of our study was to  
188 assess PwPD speaking two languages in parallel, we did not separate PwPD into subgroups for our  
189 analyses. All participants underwent the same non-invasive examinations. PwPD were assessed  
190 twice, *off* and *on* medication, respectively: (i) at least twelve hours after withdrawal from all PD  
191 medications and (ii) between 45-60 minutes after administration of the patient's usual morning dose  
192 of medication. The levodopa-equivalent doses (LED) for this intake were calculated according to  
193 reported protocols (Jost et al., 2023; Schade et al., 2020; Tomlinson et al., 2010).

#### 194 ***Clinical examinations***

195 The Movement Disorders Society Unified Parkinson's Disease Rating Scale – MDS-UPDRS (Goetz et  
196 al., 2008) – was used for the neurological assessment: the motor part (section 3) was performed  
197 twice with the PwPD, *off* and *on* medication. During the *on-medication* state, the non-motor (section  
198 1.A) and motor complication (section 4) parts of the MDS-UPDRS were administered, along with the

199 Montreal Cognitive Assessment – MoCA (Nasreddine et al., 2005) – and the Clinical Global  
200 Impression of Dysarthria Severity – CGI-S scale (Busner & Targum, 2007).

201 The Frenchay Dysarthria Assessment, version 2 – FDA-2 (Enderby & Palmer, 2008) – was performed  
202 to assess oromotor function. Speech intelligibility was rated following the instructions of the FDA-2  
203 (Enderby & Palmer, 2008). Word and sentence sets were adapted into French (Ghio et al., 2020) and  
204 Portuguese (Cardoso et al., 2017). More specifically, the general procedure was as follows: ten words  
205 (out of 101 for French, 109 for Portuguese) and ten sentences (out of 50 for French, 60 for  
206 Portuguese) were randomly selected from the sets and presented to the participants, who read them  
207 aloud. The speech/language pathologists/therapists (SLP/Ts) who carried out the FDA-2 assessment  
208 rated the correct words and sentences on the spot; they also rated intelligibility based on a short  
209 conversation with the participant. The scoring for the words and sentences was: 0 = fewer than 5  
210 words/sentences understood correctly; 1 = five to six words/sentences; 2 = seven to nine  
211 words/sentences; 3 = ten words/sentences understood with some effort; 4 = ten words/sentences  
212 easily understood. The scoring for the conversation was: 0 = unintelligibility; 1 = some words  
213 understood; 2 = severely distorted (the patient can be understood half the time and has to repeat  
214 often); 3 = abnormal but intelligible (the patient has to repeat occasionally); 4 = normal. The speech  
215 intelligibility score we used here refers to the sum of these three assessments (maximum score = 3  
216 tasks\*4 = 12 for normal intelligibility; minimum score = 3 tasks\*0 = 0 for unintelligible speech).

217 The overall assessment of the control participants was like that of the PwPD (except MDS-UPDRS  
218 section 4).

### 219 ***Patient-reported outcome measures***

220 Self-assessments were used to obtain information on the functional impact of the patient's  
221 speech/communication impairment and to provide patient-reported outcome measures (PROMs).  
222 The first set of questionnaires assessed the general quality of life and the psychosocial impact of

223 dysarthria: the 39-item Parkinson's Disease Questionnaire - PDQ-39 (Peto et al., 1995), adapted into  
224 European French and Portuguese; and the Dysarthria Impact Profile - DIP (Walshe et al., 2009),  
225 adapted into European French (Atkinson-Clement et al., 2019; Letanneux et al., 2013) and  
226 Portuguese (Cardoso et al., 2018). A second set assessed the patient's self-evaluation of their voice  
227 and speech: the 30-item Voice Handicap Index - VHI-30 (Jacobson et al., 1997), adapted into  
228 European French (Woisard et al., 2004) and Portuguese (Guimaraes et al., 2017; Guimarães &  
229 Abberton, 2004); and the Patient Global Impression of dysarthria Severity - PGI-S (Hurst & Bolton,  
230 2004). All self-evaluations were administered with PwPD on medication and with controls.

### 231 ***Acoustic recording procedure***

232 Acoustic data were collected in quiet rooms in the neurology wards of university hospitals in Aix-en-  
233 Provence, France, and Lisbon, Portugal, using specialized equipment (EVA2© system, SCLab, Aix-en-  
234 Provence, France; <http://www.sqlab.fr/>; a Marantz PMD661 MKII recorder, USA; and a DPA 4288  
235 CORE Directional Flex Headset microphone). The distance between the participant's mouth and the  
236 head-mounted microphone was kept consistent across participants to range from three to five  
237 centimeters. It was positioned at an angle of 45°-90° to the side of the lip angle, as recommended.  
238 No sound-treated recording booths were available in the neurological wards. The noise floor was not  
239 measured, but the experimental rooms were specifically chosen to prevent noise pollution from  
240 affecting the audio signals. Two researchers specialized in movement disorders in each country  
241 carried out the overall protocol: two specialized SLP/Ts in Portugal, one specialized SLP/T, and a  
242 specialized psycholinguist in France. The researchers were not blind to medication conditions (*off* or  
243 *on*). All participants were instructed to perform speech tasks at a comfortable volume and pitch to  
244 avoid straining their voices. The researchers all used the same instructions from the shared case  
245 report form to present the tasks to the participants. Participants were recorded while performing  
246 non-speech movements and speech tasks to allow several acoustic parameters to be calculated. The  
247 non-speech movement tasks included: (i) the maximally-sustained vowel /a/; (ii) production of a 3-

248 second sustained vowel /a/; and (iii) an oral diadochokinesis (DDK), namely the sequential motion  
249 rate task requiring the repetition of the tri-syllable pseudo-word /pataka/at the fastest rate possible.  
250 The speech task involved: (iv) reading aloud French (Fougeron & Smith, 1993, 1999) and Portuguese  
251 (Cruz-Ferreira, 1995, 1999) versions of Aesop's fable "The North Wind and the Sun."

### 252 ***Acoustic recording pre-processing***

253 The audio files were segmented, annotated, and analyzed with Praat software (Boersma & Weenink,  
254 2018) to calculate the dependent variables (**Table 1**).

#### 255 *TABLE 1 ABOUT HERE*

256 The maximum phonation time (MPT) was estimated from the maximally sustained vowel, as it is an  
257 efficient indicator of the coordination between the phonatory and respiratory systems. The  
258 participants were instructed to sustain the vowel /a/ twice at a comfortable voice amplitude and  
259 pitch level after maximum inspiration (Midi et al., 2008). The longer duration was selected from the  
260 two trials.

261 Pre-processing parameters for the 3-second sustained vowel /a/ production included a sampling at  
262 standard spectrum Praat settings (view range: 0-5000 Hz), F0 settings at 60-400 Hz (Rusz et al., 2011),  
263 a cross-correlation Praat method for pitch/voice analysis, the window defined in most stable  
264 segments, regardless of its location, and window length with at least 110 cycles (2-sec window if  
265 possible). The beginning (onset) and final (offset) of steady vowels are subject to changes in  
266 aerodynamic and muscular parameters, resulting in elevated jitter and shimmer values.  
267 Consequently, the most stable regions of the voice signals are usually selected for acoustic analysis  
268 (Olszewski et al., 2011). In our analyses, we discarded 200 ms from the onset and offset of the  
269 vowels. Periodicity (*i.e.*, fundamental frequency, or F0) was calculated by averaging the mean F0  
270 across the 3 trials of the vowel for each participant (Yu et al., 2007). Jitter (short-term, cycle-to-cycle  
271 variability in vocal fold vibration frequency) and shimmer (short-term, cycle-to-cycle variability in

272 vocal fold vibration amplitude) represent measures of altered stability of the steady vowel: low jitter  
273 and shimmer values are associated with an ability to maintain periodic vibration (Baken & Orlikoff,  
274 2000; Olszewski et al., 2011). The harmonic-to-noise ratio (HNR) is the ratio between the signal's  
275 total energy and the noise components' energy: the lower the HNR, the more noise in the voice;  
276 higher HNR values are associated with normal voices. HNR is evaluated as the ratio of the inharmonic  
277 (1500–4500 Hz) to the harmonic (70–4500 Hz) spectral energy (Olszewski et al., 2011).

278 In the oral DDK task, from which sequential motion rate can be calculated (Kent, 2015; Pierce et al.,  
279 2013), participants repeated a tri-syllable pseudoword, which provided data to measure several  
280 variables involved in oromotor articulatory control (Gadesmann & Miller, 2008; Lowit et al., 2018). In  
281 this task, participants repeat the syllables as quickly as possible for 30 seconds at a comfortable pitch  
282 and volume (Midi et al., 2008). The syllables for the DDK task were used to assess three major  
283 articulators, *i.e.*, the lips and the tip and dorsum of the tongue (Ziegler, 2002). Segmentation was  
284 conducted to place cursors on the audio file at the beginning and end of sound sequences to exclude  
285 silent pauses (mainly inspirations) from the total duration of the task to determine the speech  
286 proportion (= speech duration/total duration). The other measures performed were the following:  
287 articulatory rate (= syllable number/speech duration), an oral DDK performance index (DDKi), defined  
288 as speech proportion/number of sound sequences, and the variation of inter-vowel intervals (VIVI),  
289 calculated as the inter-vowel duration SD/inter-vowel duration mean.

290 For the reading task, the automatic detection of speech utterances was done using the same Praat  
291 script used for the DDK task. A specific Praat script (ProsodyPro) was then applied to extract and  
292 calculate speech duration, mean fundamental frequency (F0) and F0 standard deviation (F0\_SD).  
293 Relative sound level pressure (SPL) and relative SPL standard deviation (SPL\_SD) were calculated in  
294 Praat using the averaging method (mean dB unit) for the above-mentioned time selection.

295

296 **Statistical analyses**

297 Data analyses were performed using the R statistical software package (R Core Team, 2013). Where  
298 appropriate, demographic, and clinical data were compared using ANOVAs and generalized linear  
299 models (men/women ratio). Multiple comparisons were adjusted using Tukey corrections, and the  
300 threshold for significance was set at  $p \leq 0.05$ . To determine the importance of acoustic data for  
301 identifying language and disease differences between groups, we used random forest models  
302 combined with permutations (rfPermute package). This approach generated decision trees ( $n=5,000$ )  
303 using a subsample of the data (i.e., the individuals) and the predictors (i.e., the acoustic variables),  
304 and identified the best cut-off values that provided the highest classification accuracy for each tree.  
305 The relative importance, or mean decrease accuracy (MDA), was then calculated after normalization  
306 as follows:

307 
$$\frac{\mu(DA)}{\sigma(DA)}$$

308 where  $\mu(DA)$  represents the mean decrease accuracy of trees (MDA) and  $\sigma(DA)$  represents the  
309 standard deviation of the decrease accuracy of trees. In other words, the importance of one  
310 predictor (i.e., one acoustic variable) is determined by calculating the difference in accuracy between  
311 the decision trees that consider this predictor in comparison to trees that do not. Finally, 1,000 new  
312 random forests were built using permutations (i.e., by randomizing the predictors' values),  
313 generating a null distribution and therefore yielding p-values. The p-values are calculated by  
314 comparing the MDA of the proper random forest to the MDA of the 1,000 permuted random forests.  
315 A p-value of 0.05 means that the proper MDA is higher than 95% of the permuted MDA.

316

317

318

319 **Results**

320 ***Population description***

321 **Table 2** summarizes the participant characteristics. Identification of exclusion criteria led us to  
322 exclude some participants from the analysis: seven PwPD and eight controls in France, and ten PwPD  
323 and nine controls in Portugal (the criteria included severe cognitive and depressive symptoms [n=12],  
324 a neurological history such as essential tremor or vascular accident [n=13], medication-induced  
325 hallucinations [n=1], no Parkinson’s disease medication [n=2], oromotor history/inconvenient dental  
326 apparatus [n=2], French-Portuguese bilinguals [n=1], study withdrawal [n=2], and missing data [n=1]).  
327 The two participant cohorts we studied did not differ in age, disease duration, or LED medication for  
328 the *on*-medication state (**Table 2.A**). However, the Portuguese-speaking participants were slightly  
329 younger than the French-speaking ( $p<0.05$ ), and the man/woman ratio was more unbalanced in the  
330 French-speaking PwPD.

331 *TABLE 2 ABOUT HERE*

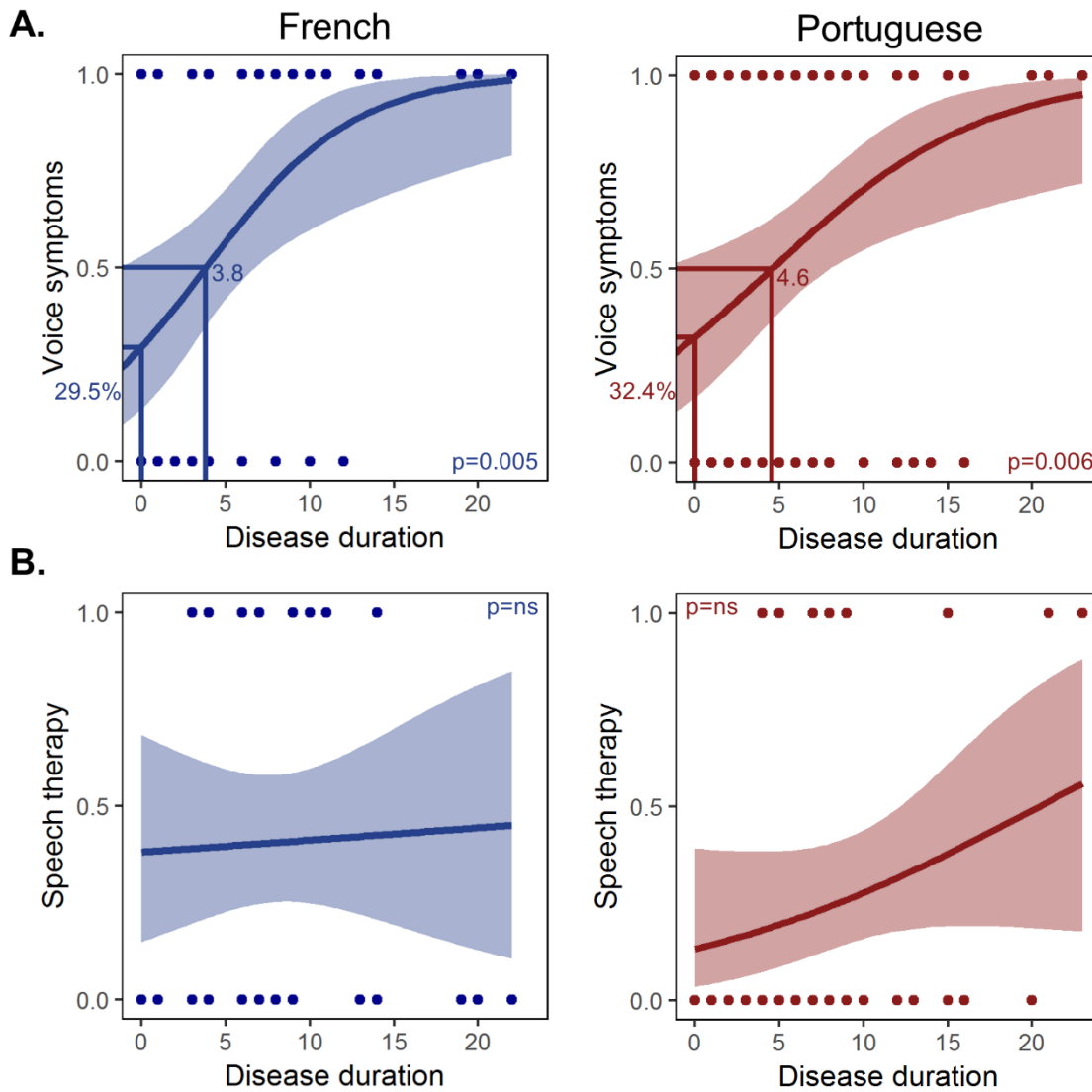
332 Logistic regressions revealed that disease duration predicted the occurrence of voice/speech  
333 complaints in both French-speaking ( $p=0.005$ ) and Portuguese-speaking ( $p=0.008$ ) PwPD: at the  
334 diagnosis, the models estimated that 29.5% (French-speaking) and 34.8% (Portuguese-speaking)  
335 PwPD already had an impairment, which increased over time to become a concern for half of the  
336 PwPD after four years of the disease’s progression (3.8 years for French-speaking PwPD, 4.6 years for  
337 Portuguese-speaking PwPD; **Figure 1.A**). Nevertheless, disease duration did not predict involvement  
338 in speech therapy in either language group (**Figure 1.B**).

339 *FIGURE 1 ABOUT HERE*

340

341





342

343 **Clinical assessments**

344 By including 'Disease' as a fixed factor of our statistical analyses, all clinical assessments (CGI-S, FDA-  
 345 2, MDS-UPDRS and MoCA) demonstrated significant ( $p < 0.001$ ) differences between PwPD and  
 346 controls (**Table 2.B**). With 'Language' as the fixed factor, no differences were found between French-  
 347 speaking and Portuguese-speaking participants for the CGI-S and part 4 of the MDS-UPDRS (PwPD-  
 348 only comparison). Significant differences were revealed for both neurological (MDS-UPDRS parts 1.A  
 349 and 3;  $p < 0.001$ ) and speech (FDA-2;  $p < 0.05$ ) assessments. A 'Disease' and 'Language' factor  
 350 interaction ( $p < 0.001$ ) was displayed *on* medication for the MDS-UPDRS motor evaluation, explained  
 351 by significantly different scores ( $p < 0.001$ ) between French-speaking and Portuguese-speaking PwPD,

352 as well as French-speaking and Portuguese-speaking controls. For the FDA-2, scores were similar for  
353 the PwPD in the two language groups, both *off* ( $p=0.8512$ ) and *on* ( $p=0.4017$ ) medication;  
354 assessments of controls were significantly different ( $p<0.001$ ), mainly driven by ‘Disease’ and  
355 ‘Language’ factor interactions ( $p<0.001$ ). The MoCA scores also differed significantly ( $p<0.001$ )  
356 between language groups, with Portuguese-speaking participants presenting lower scores than  
357 French-speaking participants; however, no interaction was found between ‘Disease’ and ‘Language’  
358 factors.

### 359 ***Patient-reported outcome measures***

360 All PROMs (MDS-UPDRS parts 1.B [non-motor daily-living activities] and 2 [motor daily-living  
361 activities], PDQ-39, PGI-S, DIP, and VHI-30) were significantly ( $p<0.01$ ) different between PwPD and  
362 controls (**Table 2.C**). No differences were found between the two groups of language speakers,  
363 except for the DIP ( $p<0.05$ ) for which Portuguese-speaking participants displayed lower scores than  
364 the French-speaking; no interaction was found between ‘Disease’ and ‘Language’ factors. A marginal  
365 interaction ( $p=0.049$ ) between factors was found for the MDS-UPDRS part 1.B; scores were similar  
366 for the PwPD ( $p=0.19$ ) and the control participants ( $p=0.85$ ) of the two language groups.

367 *TABLE 3 ABOUT HERE*

### 368 ***Acoustic parameters***

369 **Table 3** summarizes the acoustic data of the studied population. Classificatory analyzes on language  
370 (**Table 4**) revealed that French-speaking and Portuguese-speaking controls could be accurately  
371 distinguished (94.8% for men and 97% for women), as well as PwPD either *off* (90.9% for men; 94.5%  
372 for women) or *on* medication (90.9% for men 92.7% for women). Interestingly, three types of  
373 patterns emerged:

374 i) *some acoustic variables distinguished French-speaking and Portuguese-speaking individuals,*  
375 *regardless of gender or population: the mean F0 (except for men PwPD on medication) and the*  
376 *shimmer of the vowel /a/, the oral DDKi (except for men controls), the relative SPL and relative*  
377 *SPL\_SD of the text reading;*

378 ii) *one variable could significantly discriminate French-speaking and Portuguese-speaking men,*  
379 *regardless of the population (controls or PwPD, off and on medication): the F0\_SD of the*  
380 *reading task;*

381 iii) *and some variables distinguished French-speaking and Portuguese-speaking individuals for*  
382 *specific populations: for men PwPD on medication, the mean harmonic-to-noise ratio (HNR) of*  
383 *the vowel /a/; for women controls, the reading task duration; and for women PwPD off*  
384 *medication, the oral DDK speech proportion.*

385 *TABLE 4 ABOUT HERE*

386 When distinguishing PwPD from controls, analyses were performed for each gender, language, and  
387 medication state (**Table 5**). Altogether, the models led to significant general accuracy that was  
388 generally higher for the French cohort (61.2% to 75%) than for the Portuguese cohort (59.7% to  
389 70.1%). While no acoustic variable was able to distinguish PwPD from controls regardless of gender,  
390 language, or medication status, three scenarios were also observed here:

391 i) *some variables distinguished PwPD from controls regardless of language: the oral DDK*  
392 *speech proportion, except for women on medication; the maximum phonation time (MPT),*  
393 *both for men PwPD off and on medication (together with French-speaking women on*  
394 *medication); the mean jitter of the vowel /a/ was found to be discriminatory for men PwPD,*  
395 *off medication for French-speaking individuals, and on medication for Portuguese-speaking*  
396 *PwPD;*

397 ii) some variables distinguished French-speaking PwPD from controls: the mean F0 and the  
398 mean HNR of the vowel /a/ for men *on* medication; the F0\_SD of the reading task for men *off*  
399 medication; and the oral DDKi for women, both *off* and *on* medication;

400 iii) some variables distinguished PwPD from controls for Portuguese-speaking individuals: the  
401 reading task duration for men *off* medication and women both *off* and *on* medication; the oral  
402 DDK articulatory rate for women *off* medication; the oral DDKi for men *off* medication; and the  
403 F0\_SD of the reading task for women *on* medication.

404 *TABLE 5 ABOUT HERE*

## 405 **Discussion**

406 As expected, French-speaking and Portuguese-speaking control participants, both men and women,  
407 could be discriminated between by five acoustic variables - the mean F0 and the shimmer of the  
408 vowel /a/ production, the oral DDKi, the relative SPL and the relative SPL\_SD of the reading task -  
409 with an accuracy of over 94%. Differences in acoustic variables between speakers of the two  
410 languages were not exacerbated in PwPD compared to controls. Therefore, acoustic signs of  
411 dysarthria appear to be language-universal, constant and homogeneous: for both French-speaking  
412 and Portuguese-speaking men, the main variables were the maximum phonation time and the oral  
413 DDK speech proportion, while jitter was less prominent; for women, it was the oral DDK speech  
414 proportion. In contrast, the identification of language-specific variables that were more affected in  
415 one language than the other was less conclusive in the speech tasks and acoustic variables studied  
416 here.

## 417 ***Voice quality markers for language comparisons***

418 The importance of a specific predictor (i.e., one acoustic variable) was determined by calculating the  
419 difference in accuracy between the decision trees that consider this predictor in comparison to trees

420 that do not. The identified acoustic variables contributed the most to the specified comparison, with  
421 statistical significance. Comparison of acoustic variables between French-speaking and Portuguese-  
422 speaking controls, both men and women (**Table 4**), showed that differences between languages  
423 appeared to be related mostly to phonation and voice quality (mean F0 and shimmer of the  
424 sustained vowel /a/ production; relative SPL and relative SPL\_SD for the reading task). These  
425 differences were also observed for PwPD, both *off* and *on* medication, suggesting that the French vs.  
426 Portuguese discrimination based upon these variables was disease-independent. One variable from  
427 the oral DDK task, the DDKi, also participated in the language distinction for most of the participants  
428 and the reading task duration for women controls only.

429 To some extent, this is consistent with early (e.g., Hanley et al., 1966) and more recent (e.g., Tucker  
430 & Wright, 2020) approaches to studying acoustic differences among languages. Hanley et al. (1966)  
431 conducted an experimental comparison of acoustic variables in three languages (American English,  
432 American Spanish, and Japanese), using reading and spontaneous speech tasks, observing different  
433 continuums of languages between tasks and acoustic variables (including F0, SPL, and variabilities of  
434 both). This study is an early example of the research development during the 20<sup>th</sup> century of using  
435 acoustic metrics to complement the description of and compare the world's languages, a research  
436 area that has been topical as of late in various fields, such as linguistics (e.g. Tucker & Wright, 2020),  
437 eco-anthropology (e.g., Maddieson, 2018), and machine learning modeling (e.g., HaCohen-Kerner &  
438 Hagege, 2015). Within these fields, the question arises as to which dimensions of languages are  
439 shared with others and which differ; here, whether indicators of voice quality are language-specific  
440 (Tucker & Wright, 2020). In a study addressing this question, the comparison of acoustic variables  
441 (mean F0, F0\_SD, HNR, jitter, shimmer) between three languages (German, Italian, Polish) confirmed  
442 the “hypothesis of intercultural or/and interlanguage differences in voice quality” (page 654) while  
443 showing that different parameters predominate in different languages (Wagner & Braun, 2003).

444 Our descriptive data contribute to this theoretical framework: F0 and shimmer appear higher in  
445 Portuguese-speaking individuals, who also produced lower relative SPL and variation (SPL\_SD) in the  
446 reading task compared to the French-speaking cohort. F0\_SD differences between languages for men  
447 also showed that French-speaking individuals had lower variability than Portuguese-speaking ones.  
448 The question remains as to how these interlanguage differences can be integrated in the case of  
449 PwPD. First, while acoustic variables are important in distinguishing controls from PwPD (see below  
450 for a discussion of this comparison), these variables are less appropriate for a cross-language  
451 comparison between French-speaking and Portuguese-speaking PwPD; this could be the case (or not)  
452 for other language comparisons, depending on the degree of similarity between their acoustic  
453 dimensions. Following this conceptualization, cross-language comparisons may lead to as many  
454 differences as languages compared, impeding generalization. This remark also underscores the  
455 absolute necessity of including control groups. Secondly, particular differences in patterns of specific  
456 acoustic variables (**Table 4**) may contribute to specific interpretations. For instance, when  
457 considering PwPD *off* medication (namely the pathological state), the oral DDK speech proportion  
458 appeared to be a variable contributing to the distinction between French-speaking and Portuguese-  
459 speaking women PwPD. This result, in conjunction with the above-mentioned contributions of the  
460 oral DDKi and the duration of the reading task to the distinction between French-speaking and  
461 Portuguese-speaking populations, suggests that the temporal organization of speech production may  
462 reflect the specificities between languages to a lesser extent. Finally, a single acoustic parameter –  
463 the HNR - made a significant contribution to separating French-speaking and Portuguese-speaking  
464 men PwPD *on* medication. Due to the erratic effect of medication on PD voice quality and the  
465 confounding factors in this comparison (language, gender, pathology, medication), it is difficult at  
466 this point to retain any robust interpretation able to disentangle language specificity rather than a  
467 medication effect. Still, these points altogether suggest that acoustic variables may be language-  
468 dependent, at least to some extent.

469 ***Speech tasks for studying language-universal acoustic markers of dysarthria in PwPD***

470 When designing our study protocol (Pinto et al., 2016), we initially planned to report in a primary  
471 analysis the main results of the project on the acoustic, prosodic, clinical, and patient-reported  
472 measures. We adjusted this plan by focusing on the present article on acoustic, clinical, and PROM  
473 measures since some data on prosodic patterns have been already reported (Cavazzini et al., 2018;  
474 Frota et al., 2021; see also below). We had determined in the study protocol three a priori  
475 hypotheses: “(1) global acoustic features are altered similarly in French and Portuguese PwPD; (2)  
476 language-specific prosodic patterns are altered differently in French and Portuguese PwPD, and (3)  
477 the impact of speech disorders on intelligibility and quality of life depends on the cultural and  
478 linguistic environment” (Pinto et al., 2016, page 3). We discuss our findings within this framework.

- 479 • *“Global acoustic features are altered similarly in French and Portuguese individuals with PD”*

480 Recent studies have brought some insights in favor of a cross-language approach for studying  
481 dysarthric speech (Kim & Choi, 2017; Liss et al., 2013; Whitehill, 2010). Perceptual studies in  
482 particular point to more similarities than differences in how dysarthria affects the speech and/or  
483 intelligibility of PwPD in different languages (Orozco-Aroyave et al., 2016; Rusz et al., 2021; Whitehill  
484 et al., 2003). According to a disease-based account (Pinto et al., 2017) this would imply that the signs  
485 of dysarthria in PwPD are constant and homogeneous across languages, and generally independent  
486 of language specificities. We indeed found this to be true for the following variables, suggesting that  
487 they may be language-universal: mean F0 and shimmer of the sustained vowel /a/ production;  
488 relative SPL and relative SPL\_SD for the reading task. Our findings show altogether that acoustic  
489 variables related to pneumo-phonetic discoordination and generally associated with non-speech tasks  
490 (MPT, oral DDK), are the most accurate way to pinpoint dysarthria dimensions at the  
491 (neuro)physiological level. MPT is a good indicator of the coordination between the phonatory and  
492 respiratory systems as it is an aerodynamic measure of vocal function related to glottic efficiency  
493 (Hirano et al., 1968; Maslan et al., 2011). In our study, MPT has been clearly identified as a strong  
494 contributor to discrimination between men controls and men PwPD. From a disease-related

495 perspective, this result concurs with the forward-symptom progression of dysarthria (Critchley, 1981;  
496 Selby, 1968), which begins with changes in the respiratory system. From a physiological point of  
497 view, the gender-related trend (*i.e.*, only for men) has also been largely demonstrated (e.g., Knuijt et  
498 al., 2019). Regarding gender differences, it is noteworthy that no variable should be considered  
499 reliable enough to distinguish PwPD from controls when considering French-speaking women, both  
500 *off* and *on* medication, as well as Portuguese-speaking women *on* medication since PD accuracy  
501 values (**Table 5**) were not significant when calculating the random forest decision models (French-  
502 speaking women *off* medication:  $p=0.31453$ ; French women *on* medication:  $p=0.68547$ ; Portuguese-  
503 speaking women *on* medication:  $p=0.12794$ ). As with oral DDK, this task requires voluntary control  
504 of exhalation during phonation, and in our case under time pressure. We found no significant  
505 involvement of oral DDK measures related to rhythmicity (articulatory rate, VIVI) to distinguish PwPD  
506 from controls, which could have been expected (Lowit et al., 2018). Still, the DDK speech proportion  
507 and the performance index contributed to this comparison. Our findings agree with the report that a  
508 diadochokinesis task appears to be more appropriate than a reading task to evaluate speech in PwPD  
509 in cross-language comparisons (Orozco-Arroyave et al., 2016).

510

- 511 • *“Language-specific prosodic patterns are altered differently in French versus Portuguese*  
512 *individuals with PD”*

513 Medication effects reported in two separate investigations - one in each language groups - yielded  
514 results on the prosodic patterns produced by the different groups in our cohort. For French-speaking  
515 individuals (Cavazzini et al., 2018), we reported participants' prosodic patterns when reading  
516 sentences with a list of items, which provided well-defined prosodic features. We hypothesized that  
517 PwPD who experienced difficulties in producing all of the F0 rises required would preserve at least  
518 the late rise (essential in conveying the information that the element was a "non-final element of a  
519 list") rather than the optional early rise (low functional load here). Our hypothesis was confirmed,



520 with the most severely affected PwPD tending to produce smaller tonal patterns with the expected  
521 prosodic phrasing – a variety observed in controls and other PwPD. As regards medication effects,  
522 the *on*-medication state appeared to influence the prosodic pattern variety in PwPD positively. From  
523 the Portuguese side (Frota et al., 2021), we investigated nuclear contours (i.e., the most prominent  
524 pitch movement within the utterance) and intonational phrasing to establish the ability of PwPD to  
525 use the prosodic categories and structures of Portuguese. Data were reported from a subgroup of  
526 our cohort using speech materials designed to elicit specific prosodic patterns, including diverse  
527 sentence types, pragmatic meanings, and prosodic phrasings. Overall, PwPD showed a decreased  
528 ability to use nuclear contours and prosodic phrasing. Medication improved intonation regardless of  
529 disease duration but did not help with dysprosodic phrasing. In turn, disease duration and motor  
530 fluctuations affected phrasing patterns but did not impact intonation. As previously mentioned (Frota  
531 et al., 2021; Rusz et al., 2021), only a few studies have investigated the phonetic (and acoustic)  
532 parameters from a more functional perspective, such as Thies et al. (2020) and Tykalova et al. (2014).  
533 In line with our study protocol, we will conduct the planned subsequent prosodic analyzes and  
534 expand our knowledge on this point.

- 535 • *“The impact of speech disorders on intelligibility and quality of life depends on the cultural*  
536 *and linguistic environment”*

537 Intelligibility scores for French-speaking and Portuguese-speaking controls on the one hand, and  
538 French-speaking and Portuguese-speaking PwPD on the other hand, did not differ (**Table 2**). French-  
539 speaking PwPD scores were slightly lower than Portuguese-speaking PwPD’, and suggested no effect  
540 of medication – contrary to Portuguese-speaking PwPD who experienced an improvement on  
541 medication to some extent. Over the last two decades, numerous studies have focused on the effects  
542 of medication (mainly L-dopa) on dysarthria in PwPD, finding only mitigated effects, ranging from no  
543 effect in the early stage of PD (*e.g.*, Skodda et al., 2010) to improvement in advanced PwPD (*e.g.*, De  
544 Letter, Santens, De Bodt, et al., 2007; De Letter, Santens, Estercam, et al., 2007); the question

545 remains a subject of study (Fabbri et al., 2017). Furthermore, intelligibility has been shown to have a  
546 modest and limited influence on functional communication (Barnish et al., 2017). Therefore, even if  
547 PwPD intelligibility is generally preserved, when combined with a mild voice impairment, PwPD can  
548 experience an alteration in their ability to communicate. Speech intelligibility depends on both the  
549 speaker and the listener (Kim, 2016; Lansford et al., 2016), and it is worth remembering that  
550 clinicians are expert listeners who may understand patients' speech better than naive listeners (e.g.,  
551 for Portuguese-speaking speakers, Carvalho et al., 2021).

552 Although clinical examinations do not always correlate with patient self-assessments (Pawlukowska  
553 et al., 2018), our study found a high degree of agreement between disease severity impressions from  
554 both clinicians (CGI-S) and patients (PGI-S), which strongly discriminated PwPD from controls,  
555 similarly across the two Portuguese-speaking and French-speaking groups. It should be  
556 acknowledged that self-assessment of speech requires patients to consider more general dimensions  
557 of speech, which can be language or culturally dependent and are not assessed by the clinician  
558 focusing on the assessment of speech motor control. All other PROMs (DIP, MDS-UPDRS parts 1.B  
559 and 2, PDQ-39, and VHI-30) also distinguished significantly between PwPD and controls, and similarly  
560 across the two languages, except for the DIP – Portuguese-speaking participants reporting  
561 significantly more severe speech symptoms than French-speaking participants. This finding suggests  
562 that the psychosocial impact of dysarthria could be a parameter that reports aspects of the  
563 culturally-supported social network and/or language. However, it should be noted that the cognitive  
564 profile of the Portuguese-speaking participants was significantly lower than that of the French-  
565 speaking PwPD, which may have contributed to the difference. Also, since culture-dependent  
566 aspects are not specific to dysarthria in PwPD, they could also underlie a cultural difference in dealing  
567 with presbyphonia (Kosztyła-Hojna et al., 2023). However, this culturally relevant factor remains  
568 speculative at this stage as it was not tested in the current study.

569 ***Are there any language specificities in acoustic markers in dysarthria in PwPD?***

570 Identifying language-specific variables that were more affected in PwPD in one language than the  
571 other was less conclusive with the speech tasks and acoustic variables studied here. In this sense, our  
572 findings contribute to the debate raised by previous work on assessing specific impacts on speech  
573 impairment according to the patient's spoken language. For instance, unique and specific measures  
574 affected by dysarthria depending on the language have been reported in Swedish and Australian  
575 English-speaking patients with multiple sclerosis (Hartelius et al., 2003). The recent comparison  
576 between American English-speaking and Korean-speaking PwPD demonstrated that different  
577 variables involved intelligibility impairment depending on the language (Kim & Choi, 2017). We found  
578 that some acoustic variables were language-specific and more affected in one language than the  
579 other, depending on the patient's gender and medication state. The French vs. Portuguese speaker  
580 comparison (**Table 4**) showed that for men PwPD *on* medication, the mean HNR was specifically  
581 discriminative.

582 In contrast, the oral DDK speech proportion was specific for women PwPD *off* medication. This can be  
583 cross-checked with the patient vs. control comparison (**Table 5**), which demonstrates that for French-  
584 speaking men, some voice quality variables were discriminative either *on* medication (the mean F0  
585 and, as seen for the other comparison, the mean HNR of the vowel /a/) or *off* medication (the F0\_SD  
586 of the reading task). This could be related to the fact that language-specific acoustic variables  
587 distinguishing speakers of the two languages were mainly related to phonation and voice quality.

588 Additionally, for French-speaking women (*off* and *on* medication) and Portuguese-speaking men and  
589 women, significant variables were mainly temporal/rhythmic, calculated from the oral DDK and the  
590 reading task duration, and connected to pneumo-phonetic coordination. However, interpretative  
591 speculation would be hazardous here since the accuracy of the classificatory analyses was borderline.

592 These findings also raise questions regarding the potential need for language-specific tasks for  
593 speech assessment and therapy. So far, language-universal findings have been identified as  
594 important for assessing and managing dysarthria in PwPD by speech and language

595 pathologists/therapists (SLP/T) unfamiliar with the language spoken by the patient. A study involving  
596 Arabic-speaking patients showed no difference between the assessments made by Arabic-speaking  
597 and (non-Arabic) Swedish-speaking SLP/T in the domains of respiration, phonation, articulation,  
598 listener comprehension, and severity of dysarthria; a significant difference was found between  
599 assessments in the “oromotor and velopharyngeal function” domain (Näsström & Schalling, 2020).  
600 This result suggests that an assessment performed by an SLP/T speaking a language different than  
601 the patient’s is possible to some extent. On the contrary, the ability to identify cultural aspects by  
602 native SLP/Ts versus professionals who do not speak the language might contribute to fine-tune the  
603 treatment of the patient. This can be considered within the framework provided by Levy and Moya-  
604 Galé (2023), who propose a “hybrid approach” when it comes to cross-language treatment: while  
605 some treatment targets such as vocal loudness may be language-universal and appropriate to use  
606 regardless of the language spoken, it is also crucial to identify which aspects of speech intelligibility  
607 are particularly affected in a given language to maximize treatment benefits (Levy & Moya-Galé,  
608 2023).

#### 609 ***The FraLusoPark project: strengths and weaknesses***

610 Dysarthria is often described as a late symptom that affects speech intelligibility and worsens with  
611 disease progression (Müller et al., 2001). However, the early stages of dysarthria do not necessarily  
612 refer to speech intelligibility alteration. In recent years, some studies have reported that dysarthria  
613 is, in fact, a precocious symptom (Moreau et al., 2016) for which specific voice/speech dimensions  
614 could be identified even in the prodromic phase of PD (Harel et al., 2004; Postuma et al., 2012). Our  
615 results agree with an early emergence since we estimated that approximately 30% of our PwPD  
616 experienced some voice/speech impairment at the time of the diagnosis (**Figure 1.A**). Along the same  
617 lines, previous studies showed that even if a large majority of PwPD (more than 80%) report  
618 increasing speech impairments with disease progression (Miller et al., 2010; Schalling et al., 2017),  
619 PwPD do not systematically undergo speech/language therapy, as shown to some extent in our study

620 **(Figure 1.B)**. Fortunately, participation in speech/language therapy has increased in recent years; it  
621 has been reported that up to 45% of PwPD have undergone speech therapy (Schalling et al., 2017).  
622 On this point, recent literature reviews recall that while medication and neurostimulation have  
623 mitigated effects on speech impairment (Brabenec et al., 2017), speech/language therapy can  
624 significantly and consistently improve speech in PwPD (Atkinson-Clement et al., 2015).

625 In clinical trials, orofacial motor functions are typically assessed through qualitative judgments on  
626 some items of the MDS-UPDRS or, more specifically, by a speech and language pathologist, *e.g.*,  
627 using the FDA-2. We observed differing results from these scales in our study between the  
628 Portuguese-speaking and the French-speaking control groups in clinical examinations (MDS-UPDRS,  
629 MoCA, FDA-2). We question whether these differences may have resulted from the inappropriate  
630 definition of inclusion criteria for the group, low sample size, or different levels of strictness of the  
631 clinicians who performed evaluations, possibly leading to inter-rater variability. For the record and  
632 future experiments, an approach using audio-video recordings of clinical assessments would allow  
633 clinicians to conduct joint consortium scoring. Despite these limitations connected to its multicenter  
634 design, our large cohort study protocol (Pinto et al., 2016) made it possible to develop (Cardoso et  
635 al., 2017, 2018; Guimaraes et al., 2017) or use (Ghio et al., 2020) speech/voice evaluation tools  
636 whose adaptation and validation were lacking in French and Portuguese, as well as providing insights  
637 on medication modulation on prosodic features (Cavazzini et al., 2018; Frota et al., 2021).

638 To conclude, the acoustic variables related to pneumo-phonetic coordination and articulation rate  
639 were the most relevant for discriminating between PwPD and controls. Maximum phonation time  
640 and oral diadochokinesis tasks appear to be the most appropriate for detecting signs of dysarthria  
641 that are largely homogeneous and language-universal. This result is quite in line with the automated  
642 approach's objective to detect universal discriminatory variables in PwPD, regardless of the language  
643 spoken (Rusz et al., 2021). Nevertheless, linguistic idiosyncrasies have also been found in the speech  
644 of PwPD (García et al., 2023), suggesting that more refined tasks and protocols, as well as more

645 specific complementary analyses are needed to further our knowledge in this domain. Beyond the  
646 implications of tuning dysarthria assessments to differences across languages, comparisons across  
647 languages also have implications for SLP/T interventions. The identification of linguistic and/or  
648 oromotor domains that are differentially affected depending on the language is critical to fine-tune  
649 SLP/Ts management of target interventions to mitigate speech and language difficulties in PwPD  
650 (Levy & Moya-Galé, 2023).

## 651 **Acknowledgements**

652 The authors would like to thank the PwPD and the healthy controls who volunteered in this study.  
653 They also thank collaborators from Brazil (Ana Teresa Britto, Tiago Attoni, Francisco Cardoso, Victor  
654 Gandra Quintas; Belo Horizonte, Brazil) and Hong Kong (Angel Chan, Hong Kong SAR, China), who  
655 participated actively in the intellectual conceptualization of the project. This study was supported by  
656 bilateral transnational funding between France and Portugal: support from the French government  
657 was provided through the French National Agency for Research (ANR – Agence Nationale de la  
658 Recherche – project number ANR-13-ISH2-0001-01) and from the Portuguese government through  
659 the Portuguese National Foundation for Science and Technology (FCT – Fundação para a Ciência e a  
660 Tecnologia – project number FCT-ANR/NEU-SCC/0005/2013). The study also benefited from the  
661 support of the French National Centre for Scientific Research (CNRS – PICS project) for international  
662 collaboration, and a grant from the National Council for Scientific and Technological Development of  
663 Brazil (Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq, Pq #316036/2021-8).  
664 The authors report no conflict of interest for this study. Finally, the authors thank Dr. Oriana Collins  
665 for her helpful English proofreading during the revision process, and the reviewers for their helpful  
666 comments along the revision process.

## 667 **Data availability statement**

668 The datasets analyzed during the current study are available from the corresponding author upon  
669 reasonable request. However, they cannot be released before the publication of subsequent  
670 analyses conducted in the framework of the FraLusoPark project.

## 671 **References**

- 672 Atkinson-Clement, C., Letanneux, A., Baille, G., Cuartero, M.-C., Véron-Delor, L., Robieux, C.,  
673 Berthelot, M., Robert, D., Azulay, J.-P., Defebvre, L., Ferreira, J., Eusebio, A., Moreau, C., & Pinto,  
674 S. (2019). Psychosocial impact of dysarthria : The patient-reported outcome as part of the clinical  
675 management. *Neurodegenerative Diseases*, 19(1), 12-21. <https://doi.org/10.1159/000499627>
- 676 Atkinson-Clement, C., Sadat, J., & Pinto, S. (2015). Behavioral treatments for speech in Parkinson's  
677 disease : Meta-analyses and review of the literature. *Neurodegenerative Disease Management*,  
678 5(3), 233-248. <https://doi.org/10.2217/nmt.15.16>
- 679 Baken, R. J., & Orlikoff, R. F. (2000). *Clinical measurement of speech and voice* (2nd ed). Singular  
680 Thomson Learning.
- 681 Barnish, M. S., Horton, S. M. C., Butterfint, Z. R., Clark, A. B., Atkinson, R. A., & Deane, K. H. O. (2017).  
682 Speech and communication in Parkinson's disease : A cross-sectional exploratory study in the UK.  
683 *BMJ Open*, 7(5), e014642. <https://doi.org/10.1136/bmjopen-2016-014642>
- 684 Becker, G., Müller, A., Braune, S., Büttner, T., Benecke, R., Greulich, W., Klein, W., Mark, G., Rieke, J.,  
685 & Thümler, R. (2002). Early diagnosis of Parkinson's disease. *Journal of Neurology*, 249(0), 1-1.  
686 <https://doi.org/10.1007/s00415-002-1309-9>
- 687 Boersma, P., & Weenink, D. (2018). *Praat : Doing phonetics by computer [Computer program]*.  
688 (Version 6.0.43) [Logiciel]. <http://www.praat.org/>
- 689 Boulenger, V., Mechtouff, L., Thobois, S., Broussolle, E., Jeannerod, M., & Nazir, T. A. (2008). Word  
690 processing in Parkinson's disease is impaired for action verbs but not for concrete nouns.  
691 *Neuropsychologia*, 46(2), 743-756. <https://doi.org/10.1016/j.neuropsychologia.2007.10.007>

692 Brabenec, L., Mekyska, J., Galaz, Z., & Rektorova, I. (2017). Speech disorders in Parkinson's disease :  
693 Early diagnostics and effects of medication and brain stimulation. *Journal of Neural Transmission*,  
694 124(3), 303-334. <https://doi.org/10.1007/s00702-017-1676-0>

695 Busner, J., & Targum, S. D. (2007). The clinical global impressions scale : Applying a research tool in  
696 clinical practice. *Psychiatry (Edgmont (Pa.: Township))*, 4(7), 28-37.

697 Canter, G. J. (1963). Speech characteristics of patients with Parkinson's disease : I. Intensity, pitch,  
698 and duration. *Journal of Speech and Hearing Disorders*, 28(3), 221-229.  
699 <https://doi.org/10.1044/jshd.2803.221>

700 Cardoso, R., Guimarães, I., Santos, H., Loureiro, R., Domingos, J., Abreu, D., Gonçalves, N., Pinto, S., &  
701 Ferreira, J. J. (2018). Psychosocial impact of Parkinson's disease-associated dysarthria : Cross-  
702 cultural adaptation and validation of the Dysarthria Impact Profile into European Portuguese: EP:  
703 DIP validation for PD. *Geriatrics & Gerontology International*, 18(5), 767-774.  
704 <https://doi.org/10.1111/ggi.13255>

705 Cardoso, R., Guimarães, I., Santos, H., Loureiro, R., Domingos, J., De Abreu, D., Gonçalves, N., Pinto,  
706 S., & Ferreira, J. (2017). Frenchay dysarthria assessment (FDA-2) in Parkinson's disease : Cross-  
707 cultural adaptation and psychometric properties of the European Portuguese version. *Journal of*  
708 *Neurology*, 264(1), 21-31. <https://doi.org/10.1007/s00415-016-8298-6>

709 Carvalho, J., Cardoso, R., Guimarães, I., & Ferreira, J. J. (2021). Speech intelligibility of Parkinson's  
710 disease patients evaluated by different groups of healthcare professionals and naïve listeners.  
711 *Logopedics Phoniatrics Vocology*, 46(3), 141-147.  
712 <https://doi.org/10.1080/14015439.2020.1785546>

713 Cavazzini, E., Pinto, S., Atkinson-Clement, C., Viallet, F., Ferreira, J. J., & Welby, P. (2018). *Preservation*  
714 *of linguistically important aspects of prosodic structure by speakers with Parkinson's disease :*  
715 *The case of French lists*. LabPhon16, Lisbon, Portugal.

716 Critchley, E. M. (1981). Speech disorders of Parkinsonism : A review. *Journal of Neurology*,  
717 *Neurosurgery & Psychiatry*, 44(9), 751-758. <https://doi.org/10.1136/jnnp.44.9.751>



718 Cruz-Ferreira, M. (1995). European Portuguese. *Journal of the International Phonetic Association*,  
719 25(2), 90-94. <https://doi.org/10.1017/S0025100300005223>

720 Cruz-Ferreira, M. (1999). Portuguese (European). In *Handbook of the International Phonetic*  
721 *Association. A guide to the use of the International Phonetic Alphabet.: Vol. Part 2: Illustrations of*  
722 *the IPA*. (p. 126-130). Cambridge University Press.

723 Darley, F. L., Aronson, A. E., & Brown, J. R. (1969a). Clusters of deviant speech dimensions in the  
724 dysarthrias. *Journal of Speech and Hearing Research*, 12(3), 462-496.  
725 <https://doi.org/10.1044/jshr.1203.462>

726 Darley, F. L., Aronson, A. E., & Brown, J. R. (1969b). Differential diagnostic patterns of dysarthria.  
727 *Journal of Speech and Hearing Research*, 12(2), 246-269. <https://doi.org/10.1044/jshr.1202.246>

728 De Letter, M., Santens, P., De Bodt, M., Van Maele, G., Van Borsel, J., & Boon, P. (2007). The effect of  
729 levodopa on respiration and word intelligibility in people with advanced Parkinson's disease.  
730 *Clinical Neurology and Neurosurgery*, 109(6), 495-500.  
731 <https://doi.org/10.1016/j.clineuro.2007.04.003>

732 De Letter, M., Santens, P., Estercam, I., Van Maele, G., De Bodt, M., Boon, P., & Van Borsel, J. (2007).  
733 Levodopa-induced modifications of prosody and comprehensibility in advanced Parkinson's  
734 disease as perceived by professional listeners. *Clinical Linguistics & Phonetics*, 21(10), 783-791.  
735 <https://doi.org/10.1080/02699200701538181>

736 Delgado-Martins, M. R. (1986). *Sept Études sur la Perception : Accent et Intonation du Portugais*.  
737 Lisboa: Instituto Nacional de Investigação Científica.

738 Di Cristo, A. (1998). Intonation in French. In *Intonation systems. A survey of twenty languages*. (Hirst  
739 D, Di Cristo A, p. 195-218). Cambridge University Press.

740 Enderby, P. M., & Palmer, R. (2008). *FDA-2 : Frenchay Dysarthria Assessment. Second Edition*. Pro-Ed  
741 (Firm). Austin, TX, USA.

742 Eyigoz, E., Courson, M., Sedeño, L., Rogg, K., Orozco-Arroyave, J. R., Nöth, E., Skodda, S., Trujillo, N.,  
743 Rodríguez, M., Rusz, J., Muñoz, E., Cardona, J. F., Herrera, E., Hesse, E., Ibáñez, A., Cecchi, G., &

744 García, A. M. (2020). From discourse to pathology : Automatic identification of Parkinson's disease  
745 patients via morphological measures across three languages. *Cortex*, 132, 191-205.  
746 <https://doi.org/10.1016/j.cortex.2020.08.020>

747 Fabbri, M., Guimarães, I., Cardoso, R., Coelho, M., Guedes, L. C., Rosa, M. M., Godinho, C., Abreu, D.,  
748 Gonçalves, N., Antonini, A., & Ferreira, J. J. (2017). Speech and voice response to a levodopa  
749 challenge in late-stage Parkinson's disease. *Frontiers in Neurology*, 8, 432.  
750 <https://doi.org/10.3389/fneur.2017.00432>

751 Favaro, A., Moro-Velázquez, L., Butala, A., Motley, C., Cao, T., Stevens, R. D., Villalba, J., & Dehak, N.  
752 (2023). Multilingual evaluation of interpretable biomarkers to represent language and speech  
753 patterns in Parkinson's disease. *Frontiers in Neurology*, 14, 1142642.  
754 <https://doi.org/10.3389/fneur.2023.1142642>

755 Fougeron, C., & Smith, C. L. (1993). French. *Journal of the International Phonetic Association*, 23(2),  
756 73-76. <https://doi.org/10.1017/S0025100300004874>

757 Fougeron, C., & Smith, C. L. (1999). French. In *Handbook of the International Phonetic Association. A*  
758 *guide to the use of the International Phonetic Alphabet: Vol. Part 2: Illustrations of the IPA* (p. 78-  
759 81). Cambridge University Press.

760 Fox, C. M., & Ramig, L. O. (1997). Vocal sound pressure level and self-perception of speech and voice  
761 in men and women with idiopathic Parkinson disease. *American Journal of Speech-Language*  
762 *Pathology*, 6(2), 85-94. <https://doi.org/10.1044/1058-0360.0602.85>

763 Frota, S. (2014). The intonational phonology of European Portuguese. In *Prosodic typology II. The*  
764 *Phonology of Intonation and Phrasing*. (Sun-Ah. Jun, p. 6-42). Oxford University Press.

765 Frota, S., Cruz, M., Cardoso, R., Guimarães, I., Ferreira, J., Pinto, S., & Vigário, M. (2021). (Dys)Prosody  
766 in Parkinson's disease : Effects of medication and disease duration on intonation and prosodic  
767 phrasing. *Brain Sciences*, 11(8), 1100. <https://doi.org/10.3390/brainsci11081100>

768 Frota, S., & Vigário, M. (2001). On the correlates of rhythmic distinctions : The European/Brazilian  
769 Portuguese case. *Probus*, 13(2). <https://doi.org/10.1515/prbs.2001.005>

770 Gadesmann, M., & Miller, N. (2008). Reliability of speech diadochokinetic test measurement.  
771 *International Journal of Language & Communication Disorders*, 43(1), 41-54.  
772 <https://doi.org/10.1080/13682820701234444>

773 García, A. M., Bocanegra, Y., Herrera, E., Moreno, L., Carmona, J., Baena, A., Lopera, F., Pineda, D.,  
774 Melloni, M., Legaz, A., Muñoz, E., Sedeño, L., Baez, S., & Ibáñez, A. (2018). Parkinson's disease  
775 compromises the appraisal of action meanings evoked by naturalistic texts. *Cortex*, 100, 111-126.  
776 <https://doi.org/10.1016/j.cortex.2017.07.003>

777 García, A. M., De Leon, J., Tee, B. L., Blasi, D. E., & Gorno-Tempini, M. L. (2023). Speech and language  
778 markers of neurodegeneration : A call for global equity. *Brain*, awad253.  
779 <https://doi.org/10.1093/brain/awad253>

780 García, A. M., & Ibáñez, A. (2023). On the replicability of action-verb deficits in Parkinson's disease.  
781 *Cortex*, 158, 1-3. <https://doi.org/10.1016/j.cortex.2022.10.008>

782 Ghio, A., Giusti, L., Blanc, E., & Pinto, S. (2020). French adaptation of the "Frenchay Dysarthria  
783 Assessment 2" speech intelligibility test. *European Annals of Otorhinolaryngology, Head and Neck*  
784 *Diseases*, 137(2), 111-116. <https://doi.org/10.1016/j.anorl.2019.10.007>

785 Gibb, W. R. G., & Lees, A. J. (1988). A comparison of clinical and pathological features of young- and  
786 old-onset Parkinson's disease. *Neurology*, 38(9), 1402-1402.  
787 <https://doi.org/10.1212/WNL.38.9.1402>

788 Goetz, C. G., Poewe, W., Rascol, O., Sampaio, C., Stebbins, G. T., Counsell, C., Giladi, N., Holloway, R.  
789 G., Moore, C. G., Wenning, G. K., Yahr, M. D., & Seidl, L. (2004). *Movement Disorder Society Task*  
790 *Force report on the Hoehn and Yahr staging scale : Status and recommendations The Movement*  
791 *Disorder Society Task Force on rating scales for Parkinson's disease. Movement Disorders*, 19(9),  
792 1020-1028. <https://doi.org/10.1002/mds.20213>

793 Goetz, C. G., Tilley, B. C., Shaftman, S. R., Stebbins, G. T., Fahn, S., Martinez-Martin, P., Poewe, W.,  
794 Sampaio, C., Stern, M. B., Dodel, R., Dubois, B., Holloway, R., Jankovic, J., Kulisevsky, J., Lang, A. E.,  
795 Lees, A., Leurgans, S., LeWitt, P. A., Nyenhuis, D., ... LaPelle, N. (2008). *Movement Disorder*

796 Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale  
797 presentation and clinimetric testing results: MDS-UPDRS: Clinimetric Assessment. *Movement*  
798 *Disorders*, 23(15), 2129-2170. <https://doi.org/10.1002/mds.22340>

799 Guimarães, I., & Abberton, E. (2004). An investigation of the Voice Handicap Index with speakers of  
800 Portuguese : Preliminary data. *Journal of Voice*, 18(1), 71-82.  
801 <https://doi.org/10.1016/j.jvoice.2003.07.002>

802 Guimaraes, I., Cardoso, R., Pinto, S., & Ferreira, J. J. (2017). The psychometric properties of the Voice  
803 Handicap Index in people with Parkinson's disease. *Journal of Voice*, 31(2), 258.e13-258.e18.  
804 <https://doi.org/10.1016/j.jvoice.2016.05.017>

805 HaCohen-Kerner, Y., & Hagege, R. (2015). *Automatic classification of spoken languages using diverse*  
806 *acoustic features*. 275-285.

807 Hanley, T. D., Snidecor, J. C., & Ringel, R. L. (1966). Some acoustic differences among languages.  
808 *Phonetica*, 14(2), 97-107. <https://doi.org/10.1159/000258520>

809 Harel, B., Cannizzaro, M., & Snyder, P. J. (2004). Variability in fundamental frequency during speech  
810 in prodromal and incipient Parkinson's disease : A longitudinal case study. *Brain and Cognition*,  
811 56(1), 24-29. <https://doi.org/10.1016/j.bandc.2004.05.002>

812 Hartelius, L., Theodoros, D., Cahill, L., & Lillvik, M. (2003). Comparability of perceptual analysis of  
813 speech characteristics in Australian and Swedish speakers with multiple sclerosis. *Folia*  
814 *Phoniatica et Logopaedica*, 55(4), 177-188. <https://doi.org/10.1159/000071017>

815 Hirano, M., Koike, Y., & Von Leden, H. (1968). Maximum phonation time and air usage during  
816 phonation. *Folia Phoniatica et Logopaedica*, 20(4), 185-201. <https://doi.org/10.1159/000263198>

817 Hlavnička, J., Čmejla, R., Tykalová, T., Šonka, K., Růžička, E., & Ruzs, J. (2017). Automated analysis of  
818 connected speech reveals early biomarkers of Parkinson's disease in patients with rapid eye  
819 movement sleep behaviour disorder. *Scientific Reports*, 7(1), 12. [https://doi.org/10.1038/s41598-](https://doi.org/10.1038/s41598-017-00047-5)  
820 017-00047-5

821 Ho, A. K., Iansek, R., Marigliani, C., Bradshaw, J. L., & Gates, S. (1999). Speech impairment in a large  
822 sample of patients with Parkinson's disease. *Behavioural Neurology*, *11*(3), 131-137.  
823 <https://doi.org/10.1155/1999/327643>

824 Hurst, H., & Bolton, J. (2004). Assessing the clinical significance of change scores recorded on  
825 subjective outcome measures. *Journal of Manipulative and Physiological Therapeutics*, *27*(1),  
826 26-35. <https://doi.org/10.1016/j.jmpt.2003.11.003>

827 Jacobson, B. H., Johnson, A., Grywalski, C., Silbergleit, A., Jacobson, G., Benninger, M. S., & Newman,  
828 C. W. (1997). The Voice Handicap Index (VHI) : Development and validation. *American Journal of*  
829 *Speech-Language Pathology*, *6*(3), 66-70. <https://doi.org/10.1044/1058-0360.0603.66>

830 Jost, S. T., Kaldenbach, M., Antonini, A., Martinez-Martin, P., Timmermann, L., Odin, P.,  
831 Katzenschlager, R., Borgohain, R., Fasano, A., Stocchi, F., Hattori, N., Kukkle, P. L., Rodríguez-  
832 Violante, M., Falup-Pecurariu, C., Schade, S., Petry-Schmelzer, J. N., Metta, V., Weintraub, D.,  
833 Deuschl, G., ... the International Parkinson and Movement Disorders Society Non-Motor Parkinson  
834 Disease Study Group. (2023). Levodopa dose equivalency in Parkinson's disease : Updated  
835 systematic review and proposals. *Movement Disorders*, *38*(7), 1236-1252.  
836 <https://doi.org/10.1002/mds.29410>

837 Kent, R. D. (2015). Nonspeech oral movements and oral motor disorders : A narrative review.  
838 *American Journal of Speech-Language Pathology*, *24*(4), 763-789.  
839 [https://doi.org/10.1044/2015\\_AJSLP-14-0179](https://doi.org/10.1044/2015_AJSLP-14-0179)

840 Kim, H. (2016). Familiarization effects on consonant intelligibility in dysarthric speech. *Folia*  
841 *Phoniatica et Logopaedica*, *67*(5), 245-252. <https://doi.org/10.1159/000444255>

842 Kim, Y., & Choi, Y. (2017). A cross-language study of acoustic predictors of speech intelligibility in  
843 individuals with Parkinson's disease. *Journal of Speech, Language, and Hearing Research*, *60*(9),  
844 2506-2518. [https://doi.org/10.1044/2017\\_JSLHR-S-16-0121](https://doi.org/10.1044/2017_JSLHR-S-16-0121)

845 Knuijt, S., Kalf, J., Van Engelen, B., Geurts, A., & De Swart, B. (2019). Reference values of maximum  
846 performance tests of speech production. *International Journal of Speech-Language Pathology*,  
847 21(1), 56-64. <https://doi.org/10.1080/17549507.2017.1380227>

848 Kosztyła-Hojna, B., Zdrojkowski, M., & Duchnowska, E. (2023). Presbyphonia as an individual process  
849 of voice change. *Journal of Voice*, 37(2), 303.e1-303.e14.  
850 <https://doi.org/10.1016/j.jvoice.2020.12.046>

851 Lansford, K. L., Berisha, V., & Utianski, R. L. (2016). Modeling listener perception of speaker similarity  
852 in dysarthria. *The Journal of the Acoustical Society of America*, 139(6), EL209-EL215.  
853 <https://doi.org/10.1121/1.4954384>

854 Letanneux, A., Walshe, M., Viallet, F., & Pinto, S. (2013). The Dysarthria Impact Profile : A preliminary  
855 French experience with Parkinson's disease. *Parkinson's Disease*, 2013, 1-6.  
856 <https://doi.org/10.1155/2013/403680>

857 Levy, E. S., & Moya-Galé, G. (2023). Revisiting dysarthria treatment across languages : The hybrid  
858 approach. *Journal of Speech, Language, and Hearing Research*, 1-10.  
859 [https://doi.org/10.1044/2023\\_JSLHR-23-00629](https://doi.org/10.1044/2023_JSLHR-23-00629)

860 Liotti, M., Ramig, L. O., Vogel, D., New, P., Cook, C. I., Ingham, R. J., Ingham, J. C., & Fox, P. T. (2003).  
861 Hypophonia in Parkinson's disease : Neural correlates of voice treatment revealed by PET.  
862 *Neurology*, 60(3), 432-440. <https://doi.org/10.1212/WNL.60.3.432>

863 Liss, J. M., Utianski, R., & Lansford, K. (2013). Crosslinguistic application of English-centric rhythm  
864 descriptors in motor speech disorders. *Folia Phoniatrica et Logopaedica*, 65(1), 3-19.  
865 <https://doi.org/10.1159/000350030>

866 Lowit, A., Marchetti, A., Corson, S., & Kuschmann, A. (2018). Rhythmic performance in hypokinetic  
867 dysarthria : Relationship between reading, spontaneous speech and diadochokinetic tasks. *Journal*  
868 *of Communication Disorders*, 72, 26-39. <https://doi.org/10.1016/j.jcomdis.2018.02.005>

869 Maddieson, I. (2018). Language adapts to environment : Sonority and temperature. *Frontiers in*  
870 *Communication*, 3, 28. <https://doi.org/10.3389/fcomm.2018.00028>

871 Maslan, J., Leng, X., Rees, C., Blalock, D., & Butler, S. G. (2011). Maximum phonation time in healthy  
872 older adults. *Journal of Voice*, 25(6), 709-713. <https://doi.org/10.1016/j.jvoice.2010.10.002>

873 Mateus, M. H. M., & de Andrade, E. (2002). *The phonology of Portuguese*. Oxford Univ. Press.

874 Midi, I., Dogan, M., Koseoglu, M., Can, G., Sehitoglu, M. A., & Gunal, D. I. (2008). Voice abnormalities  
875 and their relation with motor dysfunction in Parkinson's disease. *Acta Neurologica Scandinavica*,  
876 0(0), 071121035509003-??? <https://doi.org/10.1111/j.1600-0404.2007.00965.x>

877 Miller, N., Deane, K. H. O., Jones, D., Noble, E., & Gibb, C. (2010). National survey of speech and  
878 language therapy provision for people with Parkinson's disease in the United Kingdom :  
879 Therapists' practices. *International Journal of Language & Communication Disorders*,  
880 100824014249025. <https://doi.org/10.3109/13682822.2010.484849>

881 Miller, N., & Lowit, A. (Éds.). (2014). *Motor speech disorders : A cross-language perspective*.  
882 Multilingual Matters.

883 Møller, M. L. H., Høj, S. H., Østergaard, K., Wallentin, M., & Højlund, A. (2023). No selective action  
884 verb impairment in patients with Parkinson's disease : Evidence from Danish patients reading  
885 naturalistic texts, a Commentary on García et al., 2018. *Cortex*, 158, 176-180.  
886 <https://doi.org/10.1016/j.cortex.2022.07.006>

887 Moreau, C., Devos, D., Baille, G., Delval, A., Tard, C., Perez, T., Danel-Buhl, N., Seguy, D., Labreuche, J.,  
888 Duhamel, A., Delliaux, M., Dujardin, K., & Defebvre, L. (2016). Are upper-body axial symptoms a  
889 feature of early Parkinson's disease? *PLOS ONE*, 11(9), e0162904.  
890 <https://doi.org/10.1371/journal.pone.0162904>

891 Moreno-Acevedo, S. A., Rios-Urrego, C. D., Vásquez-Correa, J. C., Ruz, J., Nöth, E., & Orozco-  
892 Arroyave, J. R. (2023). Language generalization using active learning in the context of Parkinson's  
893 disease Classification. In K. Ekštejn, F. Pártl, & M. Konopík (Éds.), *Text, Speech, and Dialogue* (Vol.  
894 14102, p. 349-359). Springer Nature Switzerland. [https://doi.org/10.1007/978-3-031-40498-6\\_31](https://doi.org/10.1007/978-3-031-40498-6_31)

895 Moya-Galé, G., Kim, Y., & Fabiano, L. (2023). Raising awareness about language- and culture-specific  
896 considerations in the management of dysarthria associated with Parkinson's disease within the

897 United States. *Journal of Speech, Language, and Hearing Research*, 1-9.  
898 [https://doi.org/10.1044/2023\\_JSLHR-23-00365](https://doi.org/10.1044/2023_JSLHR-23-00365)

899 Müller, J., Wenning, G. K., Verny, M., McKee, A., Chaudhuri, K. R., Jellinger, K., Poewe, W., & Litvan, I.  
900 (2001). Progression of dysarthria and dysphagia in postmortem-confirmed Parkinsonian disorders.  
901 *Archives of Neurology*, 58(2), 259. <https://doi.org/10.1001/archneur.58.2.259>

902 Nasreddine, Z. S., Phillips, N. A., Bäckström, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings,  
903 J. L., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA : A brief screening tool for  
904 mild cognitive impairment. *Journal of the American Geriatrics Society*, 53(4), 695-699.  
905 <https://doi.org/10.1111/j.1532-5415.2005.53221.x>

906 Näsström, A.-K., & Schalling, E. (2020). Development of a method for assessment of dysarthria in a  
907 foreign language : A pilot study. *Logopedics Phoniatrics Vocology*, 45(1), 39-48.  
908 <https://doi.org/10.1080/14015439.2019.1650392>

909 Olszewski, A. E., Shen, L., & Jiang, J. J. (2011). Objective methods of sample selection in acoustic  
910 analysis of voice. *Annals of Otology, Rhinology & Laryngology*, 120(3), 155-161.  
911 <https://doi.org/10.1177/000348941112000303>

912 Orozco-Arroyave, J. R., Hönig, F., Arias-Londoño, J. D., Vargas-Bonilla, J. F., Daqrouq, K., Skodda, S.,  
913 Rusz, J., & Nöth, E. (2016). Automatic detection of Parkinson's disease in running speech spoken  
914 in three different languages. *The Journal of the Acoustical Society of America*, 139(1), 481-500.  
915 <https://doi.org/10.1121/1.4939739>

916 Pawlukowska, W., Szylińska, A., Kotłęga, D., Rotter, I., & Nowacki, P. (2018). Differences between  
917 subjective and objective assessment of speech deficiency in Parkinson disease. *Journal of Voice*,  
918 32(6), 715-722. <https://doi.org/10.1016/j.jvoice.2017.08.018>

919 Peto, V., Jenkinson, C., Fitzpatrick, R., & Greenhall, R. (1995). The development and validation of a  
920 short measure of functioning and well being for individuals with Parkinson's disease. *Quality of*  
921 *Life Research*, 4(3), 241-248. <https://doi.org/10.1007/BF02260863>



922 Pierce, J. E., Cotton, S., & Perry, A. (2013). Alternating and sequential motion rates in older adults :  
923 *Alternating and sequential motion rates in older adults. International Journal of Language &*  
924 *Communication Disorders, 48(3), 257-264.* <https://doi.org/10.1111/1460-6984.12001>

925 Pinto, S., Cardoso, R., Sadat, J., Guimarães, I., Mercier, C., Santos, H., Atkinson-Clement, C., Carvalho,  
926 J., Welby, P., Oliveira, P., D'Imperio, M., Frota, S., Letanneux, A., Vigario, M., Cruz, M., Martins, I.  
927 P., Viallet, F., & Ferreira, J. J. (2016). Dysarthria in individuals with Parkinson's disease : A protocol  
928 for a binational, cross-sectional, case-controlled study in French and European Portuguese  
929 (FraLusoPark). *BMJ Open, 6(11), e012885.* <https://doi.org/10.1136/bmjopen-2016-012885>

930 Pinto, S., Chan, A., Guimarães, I., Rothe-Neves, R., & Sadat, J. (2017). A cross-linguistic perspective to  
931 the study of dysarthria in Parkinson's disease. *Journal of Phonetics, 64, 156-167.*  
932 <https://doi.org/10.1016/j.wocn.2017.01.009>

933 Postuma, R. B., Lang, A. E., Gagnon, J. F., Pelletier, A., & Montplaisir, J. Y. (2012). How does  
934 parkinsonism start? Prodromal parkinsonism motor changes in idiopathic REM sleep behaviour  
935 disorder. *Brain, 135(6), 1860-1870.* <https://doi.org/10.1093/brain/aws093>

936 R Core Team. (2013). *R: A language and environment for statistical computing.* [Logiciel]. R  
937 Foundation for Statistical Computing. <http://www.R-project.org/>

938 Ruz, J., Cmejla, R., Ruzickova, H., & Ruzicka, E. (2011). Quantitative acoustic measurements for  
939 characterization of speech and voice disorders in early untreated Parkinson's disease. *The Journal*  
940 *of the Acoustical Society of America, 129(1), 350-367.* <https://doi.org/10.1121/1.3514381>

941 Ruz, J., Cmejla, R., Tykalova, T., Ruzickova, H., Klempir, J., Majerova, V., Picmausova, J., Roth, J., &  
942 Ruzicka, E. (2013). Imprecise vowel articulation as a potential early marker of Parkinson's disease :  
943 Effect of speaking task. *The Journal of the Acoustical Society of America, 134(3), 2171-2181.*  
944 <https://doi.org/10.1121/1.4816541>

945 Ruz, J., Hlavnička, J., Novotný, M., Tykalová, T., Pelletier, A., Montplaisir, J., Gagnon, J., Dušek, P.,  
946 Galbiati, A., Marelli, S., Timm, P. C., Teigen, L. N., Janzen, A., Habibi, M., Stefani, A., Holzknrecht, E.,  
947 Seppi, K., Evangelista, E., Razu, A. L., ... Šonka, K. (2021). Speech biomarkers in rapid eye

948 movement sleep behavior disorder and Parkinson disease. *Annals of Neurology*, ana.26085.  
949 <https://doi.org/10.1002/ana.26085>

950 Sapir, S. (2014). Multiple factors are involved in the dysarthria associated with Parkinson's disease : A  
951 review with implications for clinical practice and research. *Journal of Speech, Language, and*  
952 *Hearing Research*, 57(4), 1330-1343. [https://doi.org/10.1044/2014\\_JSLHR-S-13-0039](https://doi.org/10.1044/2014_JSLHR-S-13-0039)

953 Schade, S., Mollenhauer, B., & Trenkwalder, C. (2020). Levodopa equivalent dose conversion factors :  
954 An updated proposal including opicapone and safinamide. *Movement Disorders Clinical Practice*,  
955 7(3), 343-345. <https://doi.org/10.1002/mdc3.12921>

956 Schalling, E., Johansson, K., & Hartelius, L. (2017). Speech and communication changes reported by  
957 people with Parkinson's disease. *Folia Phoniatrica et Logopaedica*, 69(3), 131-141.  
958 <https://doi.org/10.1159/000479927>

959 Scimeca, S., Amato, F., Olmo, G., Asci, F., Suppa, A., Costantini, G., & Saggio, G. (2023). Robust and  
960 language-independent acoustic features in Parkinson's disease. *Frontiers in Neurology*, 14,  
961 1198058. <https://doi.org/10.3389/fneur.2023.1198058>

962 Selby, G. (1968). Parkinson's disease. In *Diseases of the Basal Ganglia* (Vinken PJ, Bruyn GW, eds, p.  
963 173-211).

964 Skodda, S., Visser, W., & Schlegel, U. (2010). Short- and long-term dopaminergic effects on dysarthria  
965 in early Parkinson's disease. *Journal of Neural Transmission*, 117(2), 197-205.  
966 <https://doi.org/10.1007/s00702-009-0351-5>

967 Thies, T., Mücke, D., Lowit, A., Kalbe, E., Steffen, J., & Barbe, M. T. (2020). Prominence marking in  
968 parkinsonian speech and its correlation with motor performance and cognitive abilities.  
969 *Neuropsychologia*, 137, 107306. <https://doi.org/10.1016/j.neuropsychologia.2019.107306>

970 Tomlinson, C. L., Stowe, R., Patel, S., Rick, C., Gray, R., & Clarke, C. E. (2010). Systematic review of  
971 levodopa dose equivalency reporting in Parkinson's disease. *Movement Disorders*, 25(15),  
972 2649-2653. <https://doi.org/10.1002/mds.23429>

973 Tucker, B. V., & Wright, R. (2020). Speech acoustics of the world's languages. *Acoustics Today*, 16(2),  
974 56. <https://doi.org/10.1121/AT.2020.16.2.56>

975 Tykalova, T., Ruzs, J., Cmejla, R., Ruzickova, H., & Ruzicka, E. (2014). Acoustic investigation of stress  
976 patterns in Parkinson's disease. *Journal of Voice*, 28(1), 129.e1-129.e8.  
977 <https://doi.org/10.1016/j.jvoice.2013.07.001>

978 Verkhodanova, V., Coler, M., Jonkers, R., & Lowie, W. (2022). How expertise and language familiarity  
979 influence perception of speech of people with Parkinson's disease. *Clinical Linguistics & Phonetics*,  
980 36(2-3), 165-182. <https://doi.org/10.1080/02699206.2021.2003433>

981 Verkhodanova, V., Coler, M., Jonkers, R., Timmermans, S., Maurits, N., De Jong, B., & Lowie, W.  
982 (2022). A cross-linguistic perspective to classification of healthiness of speech in Parkinson's  
983 disease. *Journal of Neurolinguistics*, 63, 101068.  
984 <https://doi.org/10.1016/j.jneuroling.2022.101068>

985 Wagner, A., & Braun, A. (2003). Is voice quality language-dependent ? Acoustic analyses based on  
986 speakers of three different languages. *Proceedings of the ICPhS 03 (International Congress of*  
987 *Phonetic Sciences)*, 651-654.

988 Walshe, M., Peach, R. K., & Miller, N. (2009). Dysarthria Impact Profile : development of a scale to  
989 measure psychosocial effects. *International Journal of Language & Communication Disorders*,  
990 44(5), 693-715. <https://doi.org/10.1080/13682820802317536>

991 Welby, P. (2006). French intonational structure : Evidence from tonal alignment. *Journal of Phonetics*,  
992 34(3), 343-371. <https://doi.org/10.1016/j.wocn.2005.09.001>

993 Whitehill, T. L. (2010). Studies of chinese speakers with dysarthria : Informing theoretical models.  
994 *Folia Phoniatica et Logopaedica*, 62(3), 92-96. <https://doi.org/10.1159/000287206>

995 Whitehill, T. L., Ma, J. K., & Lee, A. S. (2003). Perceptual characteristics of Cantonese hypokinetic  
996 dysarthria. *Clinical Linguistics & Phonetics*, 17(4-5), 265-271.  
997 <https://doi.org/10.1080/0269920031000080082>

998 Woisard, V., Bodin, S., & Puech, M. (2004). [The Voice Handicap Index : Impact of the translation in  
999 French on the validation]. *Revue De Laryngologie - Otologie - Rhinologie*, 125(5), 307-312.

1000 World Medical Association Declaration of Helsinki : Ethical principles for medical research involving  
1001 human subjects. (2013). *JAMA*, 310(20), 2191. <https://doi.org/10.1001/jama.2013.281053>

1002 Yu, P., Garrel, R., Nicollas, R., Ouaknine, M., & Giovanni, A. (2007). Objective voice analysis in  
1003 dysphonic patients : New data including nonlinear measurements. *Folia Phoniatica et*  
1004 *Logopaedica*, 59(1), 20-30. <https://doi.org/10.1159/000096547>

1005 Ziegler, W. (2002). Task-related factors in oral motor control : Speech and oral diadochokinesis in  
1006 dysarthria and apraxia of speech. *Brain and Language*, 80(3), 556-575.  
1007 <https://doi.org/10.1006/brln.2001.2614>

1008

#### 1009 **Figure caption**

1010 **Figure 1.** Relationships between disease duration and (A) self-perception of voice symptoms by the  
1011 patients, and (B) their participation in speech/language therapy.

1012 Disease duration is reported in years on the x-axis. Logistic regressions were performed, based on  
1013 yes/no answers from the PwPD during the anamnesis interview. At the disease onset (*i.e.*, disease  
1014 duration = 0), significant correlations were reported between disease duration and self-reported voice  
1015 symptoms: 29.5% of French-speaking PwPD ( $p=0.005$ ) and 34.8% of Portuguese-speaking PwPD  
1016 ( $p=0.008$ ) reported a voice impairment (**A**). No relation ( $p=ns$ , non significant) between disease  
1017 duration and participation in speech/language therapy was found (**B**).

**Table 1.** Functional PD signs related to the alteration of acoustic parameters calculated from the non-speech movement and speech tasks.

Non-speech and speech tasks	Calculated Parameters	Related (dys)functions
Sustained vowel /a/ production	1. Maximal Phonation Time (MPT), in seconds	<i>Pneumophonic discoordination</i>
<i>PRAAT script: get measurements.praat → original script created by Christan Kroos, Rikke Bundgaard-Nielsen, Michael Tyler. Modified by Mark Antoniou adapted by Jasmin Sadat. <a href="http://web.mit.edu/zqi/www/uploads/1/4/8/9/14891652/get_measurements.praat">http://web.mit.edu/zqi/www/uploads/1/4/8/9/14891652/get_measurements.praat</a></i>		
Three-second sustenance of vowel /a/	2. Mean fundamental frequency (F0), in Hz 3. Jitter (cycle to cycle F0 variation), in % 4. Shimmer (cycle to cycle SPL variation), in dB 5. Harmonics-to-noise ratio (HNR), in %	<i>Dysphonia</i> <i>Roughness</i> <i>Breathiness</i> <i>Hoarseness</i>
<i>PRAAT script: get measurements.praat → original script created by Christan Kroos, Rikke Bundgaard-Nielsen, Michael Tyler modified by Mark Antoniou adapted by Jasmin Sadat. <a href="http://web.mit.edu/zqi/www/uploads/1/4/8/9/14891652/get_measurements.praat">http://web.mit.edu/zqi/www/uploads/1/4/8/9/14891652/get_measurements.praat</a></i>		
Oral diadochokinesis (DDK)	6. Speech proportion (= speech duration/total duration of the session) 7. Articulatory rate (= syllable number/speech duration, in syllables/second) 8. Oral DDK performance Index (DDKi = speech proportion/number of breath groups) 9. Variation of inter-vowel intervals (VIVI = inter-vowel duration SD/inter-vowel duration mean)	<i>Pneumophonic discoordination</i> <i>Dysrhythmia</i> <i>Pneumophonic discoordination</i> <i>Dysrhythmia</i>
<i>Praat Script (Syllable Nuclei): Copyright (C) 2008, Nivja de Jong and Ton Wempe. <a href="https://sites.google.com/site/speechrate/Home/praat-script-syllable-nuclei-v2">https://sites.google.com/site/speechrate/Home/praat-script-syllable-nuclei-v2</a></i>		
Text read aloud	10. Speech duration, in seconds 11. Mean fundamental frequency (F0), in Hz 12. F0 standard deviation (F0_SD), in Hz 13. Relative sound pressure level (SPL), in dB 14. Relative SPL standard deviation (SPL_SD), in dB	<i>Bradylalia</i> <i>Pitch alteration</i> <i>Monopitch</i> <i>Hypophonia</i> <i>Monoloudness</i>
<i>Praat Script (Syllable Nuclei): Copyright (C) 2008, Nivja de Jong and Ton Wempe. <a href="https://sites.google.com/site/speechrate/Home/praat-script-syllable-nuclei-v2">https://sites.google.com/site/speechrate/Home/praat-script-syllable-nuclei-v2</a> <i>Praat Script (ProsodyPro) : Xu, Y. (2005-2010). ProsodyPro.praat. Available from: <a href="http://crdo.fr/crdo000723">http://crdo.fr/crdo000723</a></i></i>		

MPT was performed twice, the longest duration was selected from the two trials for analyses. The three-second sustenance of vowel /a/ was performed three times, and voice parameters were calculated by averaging across the three trials of the vowel for each participant. The oral DDK task and the conversation were performed once.

**Table 2.** Description of the study cohort.

	French participants		Portuguese participants		Statistical comparisons by factor		
	HC	PD	HC	PD	Disease	Language	Interaction
<i>Screened</i>	N = 68	N = 64	N = 74	N = 84			
<b><i>Retained for analyses</i></b>	<b>N = 60</b>	<b>N = 57</b>	<b>N = 64</b>	<b>N = 75</b>			
<b>A. Demographics and medication</b>							
Age ± SD (years)	66.2 ± 7.2	69.1 ± 8.1	64.5 ± 11.4	65.9 ± 10.3	ns	*	ns
Men/Women	28/32	40/17	30/34	37/38	ns	ns	ns
Disease duration ± SD (years)	-	6.3 ± 5.1	-	7.1 ± 5.4	-	ns	-
LED ± SD (mg)	-	283.3 ± 139.5	-	273.1 ± 145.9	-	ns	-
<b>B. Clinical assessments</b>							
<b>CGI-S</b>	1.1 ± 0.3	3.3 ± 1.3	1.1 ± 0.4	2.5 ± 1.1	***	ns	ns
<b>FDA-2</b>							
<i>off</i> medication	100.8 ± 3.3	86.4 ± 11.1	95 ± 5	87.5 ± 7.8	***	*	***
<i>on</i> medication		89.4 ± 10.1		91.3 ± 6.5	***	*	***
Intelligibility ( <i>off</i> )	11.9 ± 0.3	10.9 ± 1.3	11.9 ± 0.5	11 ± 1.4	***	ns	ns
Intelligibility ( <i>on</i> )		10.8 ± 1.7		11.5 ± 0.9	***	*	**
<b>MDS-UPDRS</b>							
Part 1.A	1.1 ± 1.1	2.1 ± 1.7	2.3 ± 2.3	3.4 ± 2.9	***	***	ns
Part 3 – <i>off</i> medication	1.2 ± 1.9	25.6 ± 14.2	11.6 ± 7.5	40.4 ± 15.9	***	***	ns
Part 3 – <i>on</i> medication		12.2 ± 9.1		31.5 ± 13.7	***	***	***
Part 4	-	3.1 ± 3.5	-	4.1 ± 3.9	-	ns	-
<b>MoCA</b>	26.7 ± 1.9	25.3 ± 2.9	24.9 ± 3.2	23.6 ± 3.3	***	***	ns
<b>C. Patient-reported self-evaluations</b>							
<b>PGI-S</b>	1 ± 0	2.6 ± 1.4	1.1 ± 0.3	2.2 ± 1.2	***	ns	ns
<b>DIP</b>	192.8 ± 21.7	179 ± 27.3	181 ± 21.9	176.3 ± 22.4	**	*	ns
<b>MDS-UPDRS</b>							
Part 1.B	3.5 ± 2.9	9.5 ± 4.1	4.1 ± 3.1	8.2 ± 4.6	***	ns	*
Part 2	0.7 ± 1.4	11.5 ± 6.2	1.2 ± 2.6	12.4 ± 8.6	***	ns	ns
<b>PDQ-39</b>	11.9 ± 11.3	38.6 ± 20.6	14.2 ± 14.1	42.4 ± 24.3	***	ns	ns
<b>VHI-30</b>	3.2 ± 4.8	22.7 ± 22.9	4.3 ± 7.4	19.8 ± 19.3	***	ns	ns

ANOVAs main effects: \*  $p \leq 0.05$ , \*\*  $p \leq 0.01$ , \*\*\*  $p \leq 0.001$ . CGI-S, clinical global impression of dysarthria severity (note: missing data for 47 French controls and 20 French patients); DIP, Dysarthria Impact Profile; FDA-2, Frenchay Dysarthria Assessment, version 2; HC, healthy controls; LED, levodopa-equivalent dose; MDS-UPDRS, Movement Disorders Society-Unified Parkinson's Disease Rating Scale; MoCA, Montreal Cognitive Assessment; *off*, without medication (at last 12 hours of medication withdrawal); *on*, with medication (at least 45 minutes following usual morning dose medication intake); PD: Parkinson's disease; PDQ-39, 39-Item Parkinson's Disease Questionnaire; PGI-S, patient global impression of dysarthria severity; SD: standard deviation; VHI-30, 30-Item Voice Handicap Index.



**Table 3.** Acoustic data of non-speech and speech tasks in healthy controls (A) and patients with Parkinson’s disease (B).

A. Healthy controls	Men		Women	
	French	Portuguese	French	Portuguese
MPT	21.81 ± 7.56	24.19 ± 8.85	15.04 ± 5.01	15.85 ± 7.54
/a/ - Mean F0	104.67 ± 15.14	123.85 ± 27.66	172.01 ± 27.34	211.49 ± 48.79
/a/ - Mean HNR	20.59 ± 5.33	20.59 ± 4.82	24.65 ± 3.47	23.62 ± 5.20
/a/ - Jitter	0.39 ± 0.24	0.51 ± 0.43	0.28 ± 0.14	0.43 ± 0.35
/a/ - Shimmer	2.67 ± 1.69	4.80 ± 2.85	1.33 ± 0.59	2.96 ± 1.48
DDK - Art. rate	5.88 ± 0.84	5.89 ± 0.85	5.29 ± 0.85	5.32 ± 0.72
DDK - Speech prop.	0.95 ± 0.02	0.95 ± 0.03	0.93 ± 0.03	0.94 ± 0.04
DDK - Index	0.14 ± 0.06	0.28 ± 0.26	0.12 ± 0.05	0.16 ± 0.07
DDK - VIVI	27.56 ± 7.52	25.60 ± 7.01	29.14 ± 8.20	24.24 ± 5.75
Text - Duration	39.93 ± 5.30	39.07 ± 4.06	39.29 ± 5.49	44.16 ± 8.73
Text - Mean F0	123.14 ± 18.81	125.39 ± 21.53	194.05 ± 23.23	190.83 ± 25.02
Text - F0_SD	24.31 ± 6.65	37.18 ± 18.44	37.74 ± 9.67	37.61 ± 9.26
Text - Rel. SPL	70.75 ± 6.99	66.11 ± 3.24	70.23 ± 6.13	66.81 ± 2.94
Text - Rel. SPL_SD	15.19 ± 1.65	10.81 ± 1.77	15.39 ± 1.29	11.51 ± 2.10

B. PD patients	Men				Women			
	French		Portuguese		French		Portuguese	
	off	on	off	on	off	on	off	on
MPT	14.51 ± 5.75	16.09 ± 6.37	16.26 ± 6.69	16.79 ± 6.76	11.51 ± 6.27	10.79 ± 4.78	15.83 ± 10.23	16.48 ± 9.03
/a/ - Mean F0	118.43 ± 27.56	122.94 ± 25.71	129.91 ± 25.38	133.55 ± 23.49	164.94 ± 24.17	179.69 ± 20.65	194.85 ± 44.14	199.29 ± 41.85
/a/ - Mean HNR	20.14 ± 6.47	21.88 ± 2.67	19.59 ± 5.69	20.42 ± 5.95	24.39 ± 2.89	24.98 ± 3.18	22.88 ± 4.55	23.65 ± 5.08
/a/ - Jitter	0.49 ± 0.29	0.38 ± 0.20	0.67 ± 0.63	0.64 ± 0.75	0.30 ± 0.14	0.33 ± 0.24	0.42 ± 0.35	0.41 ± 0.22
/a/ - Shimmer	2.26 ± 0.85	2.23 ± 1.24	4.69 ± 3.40	4.71 ± 3.14	1.36 ± 0.50	1.52 ± 0.89	2.81 ± 1.87	2.92 ± 2.00
DDK - Art. rate	5.49 ± 0.71	5.41 ± 0.87	5.44 ± 0.82	5.54 ± 0.81	5.47 ± 0.60	5.54 ± 0.66	5.47 ± 1.15	5.39 ± 0.81
DDK - Speech prop.	0.91 ± 0.04	0.89 ± 0.07	0.90 ± 0.08	0.91 ± 0.05	0.86 ± 0.10	0.90 ± 0.06	0.92 ± 0.06	0.93 ± 0.05
DDK - Index	0.10 ± 0.05	0.09 ± 0.05	0.13 ± 0.06	0.15 ± 0.07	0.07 ± 0.04	0.09 ± 0.07	0.19 ± 0.16	0.16 ± 0.07

<b>DDK - VIVI</b>	26.73 ± 7.15	29.34 ± 11.28	23.27 ± 6.23	24.90 ± 5.65	28.56 ± 9.29	27.03 ± 6.96	23.74 ± 6.04	24.76 ± 6.31
<b>Text - Duration</b>	40.57 ± 6.09	39.41 ± 5.47	45.45 ± 15.40	45.72 ± 14.89	42.51 ± 5.65	41.15 ± 11.69	44.01 ± 11.01	43.52 ± 9.61
<b>Text - Mean F0</b>	122.27 ± 22.91	133.84 ± 34.56	127.62 ± 22.59	129.40 ± 21.03	188.11 ± 20.68	178.15 ± 28.13	180.00 ± 26.43	184.91 ± 23.90
<b>Text - F0_SD</b>	19.45 ± 5.19	21.43 ± 6.27	32.65 ± 13.16	34.77 ± 13.23	31.71 ± 7.95	30.21 ± 10.35	36.64 ± 11.08	32.18 ± 9.02
<b>Text - Rel. SPL</b>	70.36 ± 6.31	71.79 ± 5.77	64.75 ± 3.37	65.16 ± 3.78	68.88 ± 7.63	68.58 ± 7.61	65.91 ± 4.04	66.07 ± 3.23
<b>Text - Rel. SPL_SD</b>	16.03 ± 1.89	1.04 ± 2.08	11.86 ± 1.76	11.70 ± 2.26	15.66 ± 1.04	15.98 ± 1.59	11.58 ± 2.01	11.78 ± 1.89

Non-speech movement tasks included: (i) the sustained vowel /a/ production, which allowed the calculation of the maximum phonation time (MPT, in seconds); (ii) the 3-seconds sustenance of the vowel /a/, which allowed the calculation of the mean fundamental frequency (F0, in hertz - Hz), jitter (%), shimmer (in decibels - dB), and the harmonics-to-noise ratio (HNR, in %); and (iii) an oral diadochokinesis (DDK), which provided the calculation of the speech proportion, the articulatory rate (in syllables/second), the oral DDK performance index, and the variation of inter-vowel intervals (VIVI). The connected speech task involved: (iv) reading aloud of short text, which allowed the calculation of the speech (text) duration, the mean F0 (Hz), the mean F0 standard deviation (F0\_SD, Hz), the relative sound pressure level (rel. SPL, dB) and the relative SPL standard deviation (rel. SPL\_SD, dB). *off*, without medication (at last 12 hours of medication withdrawal); *on*, with medication (at least 45 minutes following usual morning dose medication intake).

**Table 4.** Contribution of acoustic parameters for distinguishing French and Portuguese individuals.

	Men			Women		
	HC	PD <i>off</i>	PD <i>on</i>	HC	PD <i>off</i>	PD <i>on</i>
<b>MPT</b>	-0.94%	-4.59%	3.24%	-3.82%	5.98%	10.88%
<b>/a/ - Mean F0</b>	<b>19.78% *</b>	<b>10.19% *</b>	9.55%	<b>33.91% **</b>	<b>22.06% **</b>	<b>20.59% *</b>
<b>/a/ - Mean HNR</b>	0.71%	3.38%	<b>17.27% *</b>	5.41%	4.93%	6.42%
<b>/a/ - Jitter</b>	7.18%	6.89%	6.56%	8.26%	4.46%	9.99%
<b>/a/ - Shimmer</b>	<b>22.62% *</b>	<b>34.64% ***</b>	<b>32.53% ***</b>	<b>46.95% ***</b>	<b>35.35% ***</b>	<b>23.23% **</b>
<b>DDK - Articulatory rate</b>	-5.44%	-2.68%	-2.47%	2.34%	-1.44%	-2.73%
<b>DDK - Speech proportion</b>	1.45%	-3.85%	-2.79%	5.51%	<b>16.78% *</b>	11.86%
<b>DDK - Index</b>	13.66%	<b>13.02% *</b>	<b>26.64% **</b>	<b>15.28% *</b>	<b>27.64% **</b>	<b>27.29% ***</b>
<b>DDK - VIVI</b>	-4.24%	7.09%	2.37%	10.51%	10.18%	-3.66%
<b>Text - Duration</b>	-6.06%	-0.25%	7.25%	<b>17.60% *</b>	0.91%	0.18%
<b>Text - Mean F0</b>	-0.95%	0.38%	3.35%	-4.29%	11.34%	3.54%
<b>Text - F0_SD</b>	<b>29.89% **</b>	<b>48.15% ***</b>	<b>46.53% ***</b>	-2.56%	0.03%	-0.27%
<b>Text - Relative SPL</b>	<b>44.67% ***</b>	<b>42.03% ***</b>	<b>37.74% **</b>	<b>33.85% ***</b>	<b>12.48% *</b>	<b>25.47% **</b>
<b>Text - Relative SPL_SD</b>	<b>63.33% ***</b>	<b>68.26% ***</b>	<b>63.09% ***</b>	<b>66.14% ***</b>	<b>52.46% ***</b>	<b>50.89% ***</b>
<b>French accuracy (p-value)</b>	92.9% ( <i>&lt;0.00001</i> )	95.0% ( <i>&lt;0.00001</i> )	92.5% ( <i>&lt;0.00001</i> )	93.8% ( <i>&lt;0.00001</i> )	100% ( <i>&lt;0.00001</i> )	94.1% ( <i>&lt;0.00001</i> )
<b>Portuguese accuracy (p-value)</b>	96.7% ( <i>&lt;0.00001</i> )	86.5% ( <i>&lt;0.00001</i> )	89.2% ( <i>&lt;0.00001</i> )	100% ( <i>&lt;0.00001</i> )	92.1% ( <i>&lt;0.00001</i> )	92.1% ( <i>&lt;0.00001</i> )
<b>General accuracy (p-value)</b>	94.8% ( <i>&lt;0.00001</i> )	90.9% ( <i>&lt;0.00001</i> )	90.9% ( <i>&lt;0.00001</i> )	97.0% ( <i>&lt;0.00001</i> )	94.5% ( <i>&lt;0.00001</i> )	92.7% ( <i>&lt;0.00001</i> )

Data are expressed as mean decrease accuracy (in %) for each acoustic variable, and according to participant sex (men, women) and population state (controls, PD patients *off* medication, PD patients *on* medication). The French and Portuguese accuracy refers to the capacity of the random forest models to identify respectively a French participant as an actual French person, and a Portuguese participant as an actual Portuguese individual. The general accuracy refers to the same capacity for the whole group of participants (*i.e.*, French and Portuguese participants). Data can be interpreted in the following manner: the higher the percentage, the more important is the variable in the random forest models that aim at discriminating French and Portuguese individuals. For example, for men controls, the mean decrease accuracy of the vowel

/a/ mean F0 is 19.78%, which means that if the vowel /a/ mean F0 was removed from the set of variables analyzed here, the accuracy of discriminating French and Portuguese participants would decrease by 19.78%; demonstrating – and confirmed by the p-value of the comparison – that this acoustic variable is of importance for such discrimination. Significant mean decrease accuracy are highlighted in grey and as follows: \*:  $0.01 < p < 0.05$ ; \*\*:  $0.001 < p < 0.01$ ; \*\*\*:  $p < 0.001$ .

**Table 5.** Contribution of acoustic parameters for distinguishing PD patients and controls.

	French				Portuguese			
	Men		Women		Men		Women	
	<i>off</i>	<i>on</i>	<i>off</i>	<i>on</i>	<i>off</i>	<i>on</i>	<i>off</i>	<i>on</i>
<b>MPT</b>	<b>43.79% ***</b>	<b>34.42% ***</b>	13.16%	<b>18.02% *</b>	<b>33.84% **</b>	<b>28.44% **</b>	0.11%	1.94%
<b>/a/ - Mean F0</b>	10.62%	<b>24.91% **</b>	1.66%	-0.43%	-2.04%	6.33%	-0.37%	-2.27%
<b>/a/ - Mean HNR</b>	4.90%	<b>15.83% *</b>	-8.35%	-11.70%	-1.83%	-2.96%	6.66%	-5.34%
<b>/a/ - Jitter</b>	<b>23.46% **</b>	-2.16%	-7.20%	-9.37%	4.73%	<b>16.19% *</b>	-5.58%	-2.25%
<b>/a/ - Shimmer</b>	12.19%	-1.53%	-7.20%	-9.09%	-5.20%	-4.35%	7.83%	-1.26%
<b>DDK - Articulatory rate</b>	3.85%	1.78%	-3.70%	-4.34%	3.36%	-5.32%	<b>18.94% *</b>	4.15%
<b>DDK - Speech proportion</b>	<b>26.50% **</b>	<b>29.87% **</b>	<b>21.35% *</b>	10.57%	<b>28.87% **</b>	<b>17.74% *</b>	<b>20.32% *</b>	7.98%
<b>DDK - Index</b>	6.92%	8.06%	<b>20.92% *</b>	<b>21.80% *</b>	<b>31.62% **</b>	12.96%	2.87%	-1.88%
<b>DDK - VIVI</b>	-2.30%	-9.77%	0.07%	-3.51%	11.99%	2.18%	2.07%	-5.63%
<b>Text - Duration</b>	-8.73%	-10.99%	2.23%	-0.39%	<b>16.92% *</b>	13.47%	<b>14.59% *</b>	<b>21.12% *</b>
<b>Text - Mean F0</b>	1.08%	-3.09%	-10.86%	-9.21%	-7.69%	-7.24%	3.24%	-10.94%
<b>Text - F0_SD</b>	<b>22.77% **</b>	10.02%	4.42%	12.04%	-0.96%	1.22%	-5.87%	<b>22.09% *</b>
<b>Text - Relative SPL</b>	12.67%	0.72%	-1.33%	-5.09%	7.54%	13.12%	3.47%	2.21%
<b>Text - Relative SPL_SD</b>	3.78%	7.18%	2.04%	-4.12%	4.52%	6.28%	0.99%	8.37%
<b>HC accuracy (p-value)</b>	75.0% (0.00001)	67.9% (0.01785)	68.8% (0.01003)	71.9% (0.00350)	66.7% (0.02139)	56.7% (0.18080)	70.6% (0.00452)	61.8% (0.06072)
<b>PD accuracy (p-value)</b>	75.0% (0.00001)	70.0% (0.00321)	52.9% (0.31453)	41.2% (0.68547)	73.0% (0.00128)	62.2% (0.04943)	65.8% (0.01677)	57.9% (0.12794)
<b>General accuracy (p-value)</b>	75.0% (0.00001)	69.1% (0.00046)	63.3% (0.02219)	61.2% (0.04272)	70.1% (0.00026)	59.7% (0.04322)	68.1% (0.00065)	59.7% (0.03818)

Data are expressed as mean decrease accuracy (in %) for each acoustic variable, and according to language (French, Portuguese), participant sex (men, women) and medication state (*off*, *on* medication). The HC and PD accuracy refers to the capacity of the random forest models to identify respectively a HC as an actual HC, and a patient as an actual PD patient. The general accuracy refers to the same capacity for the whole group of participants (*i.e.*, HC and PD patients). Data can be interpreted in the following manner: the higher the percentage, the more important is the variable in the random forest models that aim at discriminating PD patients from HC. For example,

for French PD patients off medication, the mean decrease accuracy of MPT is 43.79%, which means that if MPT was removed from the set of variables analyzed here, the accuracy of discrimination PD patients from HC would decrease by 43.79%; demonstrating – and confirmed by the p-value of the comparison – that MPT is of great importance for such discrimination. Significant mean decrease accuracy are highlighted in grey and as follows: \*:  $0.01 < p < 0.05$ ; \*\*:  $0.001 < p < 0.01$ ; \*\*\*:  $p < 0.001$ .