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ABSTRACT

Cross-linguistic studies aim at determining the similarities and differences in speech production by uncovering linguistic adaptations to specific constraints and environments. In the field of motor speech disorders, such a cross-language approach could be of great interest to understand not only the deficits of speech production that are induced by the pathology, but also the difficulties that are induced by the linguistic constraints specific to the patients' language. From a more clinical point of view, cross-linguistic studies should specifically focus on the relationship between speech disorders and speech intelligibility. The aim of this opinion article is to identify the currently scarce theoretical and clinical avenues for cross-linguistic studies of dysarthria in Parkinson's disease, and to establish guidelines that would lead future research in this direction. In turn, the practical and behavioral management of dysarthria in Parkinson's disease has so far only focused on the 'universal' dimensions of speech production and feedback (*e.g.*, treatment of loudness and dysprosody). Such approaches could benefit immensely from proper recommendations that would be more 'language-driven' and individually adapted to the patients' language environment. An additional factor to consider for a better understanding and treatment of dysarthria in PD is the role of adjustment and cultural identity.

1. Introduction

1.1. The rationale for studies on dysarthria

Speech motor control is an important part of successful communication. The breakdown of such motor control can result in speech impairment, such as ***dysarthria***, a speech disorder present in most movement disorders. '*Dysarthria is a collective name for a group of speech disorders resulting from disturbances in muscular control over the speech mechanism due to damage of the central or peripheral nervous system. It designates problems in oral communication due to paralysis, weakness, or incoordination of the speech musculature.*' (Darley, Aronson, & Brown, 1969b, p. 246). The description and classification of dysarthrias, provided by Darley, Aronson and Brown in their pioneering work on motor speech disorders in neurological movement disorders (Darley, Aronson, & Brown, 1969a; Darley et al., 1969b), still represents a consensual, easy-to-understand and practical way to describe speech impairment in movement disorders. Dependent on the location of the nervous system disruption (central or peripheral) that affects muscular control, dysarthria can be further classified into several subtypes (Darley et al., 1969a, 1969b; Duffy, 2005, 2013): flaccid (bulbar lesion and/or dysfunction), spastic (pseudo-bulbar), ataxic (cerebellar), hypokinetic (basal ganglia), hyperkinetic (basal ganglia) and mixed (diffuse).

Among other possibilities, there are two principal ways of examining dysarthria in movement disorders: On the one hand, one can adopt what could be called a *neurological disease-based approach*, which implies that pathophysiological processes are at the origin of the motor signs that contribute, maybe exclusively, to speech disorders; On the other

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hand, a *(neuro)linguistic-based approach* considers that motor speech disorders are the result of alterations dependent on modifications of linguistic processes that have emerged along the progression of the disease. From the former point of view (*i.e.*, disease-based), dysarthria needs to be ***assessed***, in order to be ***managed***; eventually, it can help the clinician and/or the researcher to understand more precisely the pathophysiology of the speech symptom and/or the disease itself as an example of variation-from-normal. From the latter perspective (*i.e.*, (neuro)linguistic-based), dysarthria can be ***studied*** and this pathological model would help to define and refine (neuro)linguistic models of speech production, especially in the case of neurodegenerative diseases that represent, *per se*, a dynamical model of progressive speech variation-from-normal across time. Biasing towards one of the two approaches would narrow the impact of the findings, and it is reasonable to argue that both approaches are complementary and much needed to provide the most thorough description and analysis of dysarthria.

Up to now, dysarthria has been assessed and studied either in clinical settings or through acoustic and other experimental analyses. Similar to the aforementioned distinction between disease- and (neuro)linguistic-based accounts, the ways to assess dysarthria differ depending on the research question: In a clinical setting, the physiological functions of articulatory muscles are principally evaluated through means of qualitative judgments by a speech and language pathologist (*e.g.*, using the Frenchay Dysarthria Assessment; Enderby, 1980; Enderby & Palmer, 2008). This assessment will establish the impact of the disease and define the pathophysiological state of the speaker to better manage speech impairments. An alternative assessment is the acoustic analysis of speech from dysarthric patients to extract quantitative measures of how the patients' speech differs from healthy speakers and to understand how neurological dysfunction impacts speech production. Importantly, though, it is still unclear in these kinds of assessments how speech breakdown in dysarthria may interact with the typological characteristics of the target language spoken by the patient. In such a context, it seems important to identify a further potential source of variation to dysarthria. Independent of how this phenomenon is assessed, managed, or studied, one needs to know which processes underlying speech production can be applied universally, and which ones are prone to cross-linguistic differences.

For instance, the conceptual level, where thoughts and messages to be expressed are constructed, is generally considered as being largely language-independent (*cf.* Levelt, 1989; but see Slobin, 1996). To date, most studies on cross-linguistic speech production have focused on lexical access, sentence construction, and phonological encoding, since these levels of processing likely show differences across languages. Probably, one reason why the role of speech motor control across languages has been largely neglected is due to the fact that motor abilities are universally shared, and thus motor execution has long been considered as modular and separate from speech planning stages. However, the shared motor and neural basis of speech production contrasts with the remarkable diversity of human languages in which speakers are actively engaging and 'training' on a daily basis. On top of that, recent studies in speech production have shed considerable doubt on the traditional dissociation between the planning and execution levels of speech processing (*e.g.*, Bell, Brenier, Gregory, Girand, & Jurafsky, 2009; Spencer & Rogers, 2005). Thus, one question that derives from this change of perspective is how motor speech breakdown, such as in dysarthria, would interact with these cross-linguistic variations, and specifically, to what extent dysarthria is affected by the language a person speaks.

1.2. The rationale for cross-linguistic studies on dysarthria

In this opinion article, we will consider the possibility that, although speech motor control is a universally shared human ability, the evolution and impact of speech disorders may depend on the linguistic and cultural environment of the patients. Alternatively, it could also be argued that there are compensation strategies that evolve together with the processes that accompany speech motor breakdown, suggesting a universal tendency for adjustments to speech disorders in patients. The rationale of carrying out cross-language studies on motor speech disorders such as dysarthria is to reveal the universal and language-specific dimensions of a patient's speech. Despite the universality of speech motor abilities, communication needs to be studied within specific cultural and linguistic environments, since long-term language-specific influences are likely to interact with its universal foundation. Research in speech production has mainly focused on unraveling the universal processes that govern the development, use, and breakdown of language processes. Only recently have researchers turned to ask how these universal principles may be modulated by and extended to the specificities of other languages (*e.g.*, Costa, Alario, & Sebastián-Gallés, 2007; Norcliffe, Harris, & Jaeger, 2015; O'Seaghdha and Chen, 2009; Sadat, Martin, Costa, & Alario, 2014). Most research in the field of the language sciences has been conducted in English, and thus one may ask whether current findings refer to language universal mechanisms or English-specific facts. An example of how articulation and speech control mechanisms differ across languages can be found when assessing voice onset times (VOTs), the interval between the release of a stop consonant occlusion and the onset of the vocal-fold vibration, across different languages. For example [p] in French has a VOT similar to a [b] in English which reveals language-specific quantitative VOT values in different languages (*e.g.*, Keating, 1984; Sancier & Fowler, 1997). Moreover, speech sounds never occur in isolation and thus additional levels such as prosody that are susceptible to language-specific differences can also influence the articulation of speech.

Overall, it remains unclear how motor speech breakdown will vary with environmental contexts, and in particular, to what extent motor speech breakdown is dependent on the properties of the specific language one speaks. Previous cross-linguistic work in the context of language pathologies has mainly focused on higher levels of language processing (*e.g.*, aphasia, dyslexia) and explored how they influence speech errors and disfluencies (for a detailed statement of the rationale for cross-language studies on motor speech disorders, *cf.* Miller, Lowit, & Kuschmann, 2014). This body of research supports the idea that predominant properties of a certain language lead to variable degrees of impairment for articulatory features when motor speech breakdown occurs. One could imagine for example that a patient speaking a language containing a large number of consonants would have acquired increased abilities in kinematic movements to control consonant production. Thus consonant production could be more preserved in patients speaking languages that are rich in consonants than in languages with significantly fewer consonants, with speech motor control and breakdown depending on the particular properties and frequency distributions of the spoken language.

1.3. The rationale for cross-linguistic studies on dysarthria in Parkinson's disease

In this paper, we focus on the particular type of hypokinetic dysarthria that is observed in patients with Parkinson's disease (PD), mainly because the specific and rather homogeneous physiopathology of the disease will allow isolating the contributions of language-dependent influences on speech impairments. In fact, speech disorders in PD dysarthria are quite consistent across patients, and can be interpreted and considered as the result of specific degenerations of identified neuronal populations. PD dysarthria characteristics are related to the main clinical signs of parkinsonism, *i.e.*, resting tremor, rigidity, and bradykinesia (associated with a proper akinesia and hypokinesia), each of those contributing to a certain extent to alterations of speech motor control. Seventy percent of the patients with PD report that their speech is impaired during the disease process (Hartelius & Svensson, 1994). Dysarthria can appear at any stage of PD, and worsens in the later stages of the disease, leading to a progressive loss of communication and a marked social isolation. After ten years of disease progression, motor symptoms are usually still improved by medication whereas axial signs such as dysarthria worsen for most patients (Klawans, 1986).

Important language-specific factors could be positional properties and distributional patterns in phonotactics, since PD patients are especially impaired regarding the initiation of movement. For example, according to a linguistic-based account, languages containing more complex word initials (*e.g.*, Czech) could pose more problems to PD patients when initiating speech than languages that have simpler word initials. Alternatively, according to a disease-based account, this feature of the Czech language would train patients' performance with more complex word initials and improve performance compared to patients speaking less consonant driven languages. Similarly, and dependent on the disease- or linguistic-based account, it could be argued that patients of agglomerative languages (*e.g.*, Turkish) will have more or less difficulties in speech motor control and parallel planning than languages with rather short syllable sized words (*e.g.*, Cantonese). There are many possible reasons that suggest language-specific differences in the assessment and impact of PD dysarthria, most of which rely on the particular distributional properties and different sound inventories of a specific language.

From a perceptual point of view, the cross-linguistic approach to studying dysarthria is concerned with the question of whether disorders of dysarthric speech may differentially disturb the perception of a given language. This problem is mainly defined by the constraints of co-occurrence patterns and contrastive sound systems in a specific language: combinations of words that frequently occur together will be easier to recognize compared to unusual expressions, and sound contrasts that are relevant for distinguishing meanings may be lost. Thus, dysarthric patients may fail to communicate important meaning differences in a certain language, but not in others in which these contrastive features are not distinctive. Consider for example the fact that different languages make different use of word stress. Unlike French, English has variable stress that can distinguish the meaning of words. One of the most evident deficits in PD speech is the flattening of the melodic curve when compared to healthy individuals (see Fig. 2). Thus, according to the linguistic-based account, one could argue that PD patients who speak English could show a melodic curve that is more preserved, since this feature serves to distinguish between different concepts in English (*e.g.*, 'IMport' vs. 'imPORT'). In contrast, patients who speak French would have no particular reason to preserve this dimension of stress intonation, since this cannot lead to the change of meaning for words in French. Alternatively, and according to the disease-based account, an equally impaired melodic curve across patients with PD, is predicted to impact the perception of English-speaking patients more than those of French-speaking patients.

2. Cross-linguistic speech dimensions to dysarthric PD speech

According to the early description of dysarthria in PD (Darley et al., 1969a), the following deviant speech dimensions have been reported: monotony of pitch, reduced stress, monotony of loudness, imprecise consonants, inappropriate silences, short rushes of speech, harsh and breathy voice, low pitch and variable rate. In fact, dysarthria in PD is a highly complex deficit resulting from multiple factors (for a review, *cf.* Sapir, 2014).

Findings from both speech production as well as speech perception research are relevant to the assessment of dysarthria in PD. Articulatory difficulties that evolve with the progression of the patients' disease can be identified in the produced speech. In addition, difficulties that are apparent in the perception of speech are usually rated by using intelligibility judgments. Both of these research streams have a tradition of cross-linguistic research that is useful to reveal specific production and perception deficits, leading to a complete assessment of PD dysarthria. Until now, research on PD dysarthria has been driven by numerous studies with patients in Germanic languages (*e.g.*, English, German), and to a lesser extent, in Romance languages (*e.g.*, French, European Portuguese). In fact, today several studies conducted in Asian (*e.g.*, Cantonese, Japanese) or Slavic (*e.g.*, Czech) languages also contribute to the understanding of PD dysarthria. However, as the populations that speech and language pathologists work with will continue to diversify, it is important to start considering whether these predominant English-based language models can be applied across all languages. It is still an open question whether the articulatory difficulties associated with PD dysarthria seen so commonly in patients speaking English (often seen as a model language; Vitevitch, Chan,

& Goldstein, 2014), will have the same consequences in speakers of other languages where sounds and prosodic properties (stress, rhythmic, tempo and intonation) vary. As a first step in this direction, it is important to empirically assess a variety of different languages before being able to generalize any speech disorders associated with PD. Thus, our opinion article further motivates the study of speech output in currently understudied languages such as Bengali (Chakraborty, Roy, Hazra, Biswas, & Bhattacharya, 2008) or Cantonese (Whitehill, 2010). This approach would help pointing out the specificities of different languages in order to generalize current ideas about speech breakdown beyond English (for an extensive overview on the sound properties of various under-studied languages (*cf.* Miller et al., 2014). In parallel, possible classification patterns for different languages need to be established to guide the systematic cross-linguistic assessment in PD dysarthria. In fact, several language-specific properties seem susceptible to how PD dysarthria manifests itself in certain languages. In what follows, we will focus on the dimensions (segmental and supra-segmental) that characterize PD dysarthria, as mentioned above, and lay out some examples leading one to consider how certain differences could possibly emerge depending on the patients' language.

2.1. Phonation

The dysfunction of respiratory muscles (Jiang, Lin, Wang, & Hanson, 1999; Murdoch, Chenery, Bowler, & Ingram, 1989; Solomon & Hixon, 1993) contributes in part to the reduction of loudness, or hypophonia (Ho, Bradshaw, Iansek, & Alfredson, 1999; Ho, Iansek, & Bradshaw, 1999; Ramig, Sapir, Fox, & Countryman, 2001), associated with a decrease in expiratory volumes (Ho, Iansek, & Bradshaw, 2001; King, Ramig, Lemke, & Horii, 1994; Metter & Hanson, 1986) and impaired self-perception of loudness (Arnold, Gehrig, Gispert, Seifried, & Kell, 2014; Ho, Bradshaw et al., 1999; Ho, Iansek et al., 1999). Dysphonia in PD corresponds to the functional abnormalities of the laryngeal vibrator that affect pitch, timbre and intensity. Perceptually, the voice of PD patients is generally harsh and breathy, due to the lack of vocal folds' adduction, and subject to rigidity and tremor (Baker, Ramig, Luschei, & Smith, 1998; Luschei, Ramig, Baker, & Smith, 1999). Acoustic measurements during sustained vowel production allow quantifying these abnormalities, *i.e.*, an increase of cycle-to-cycle F0 (jitter) and intensity (shimmer) instability, and changes related to tremor. Regarding pitch, perceptual analyses and acoustic measurements generally find mitigated results. Fundamental frequency (F0) does not only vary between healthy speakers and dysarthric patients of the same language, but also within the same speakers dependent on medication intake for example. F0 can be lowered, as the initial result of dopamine deficiency, leading to subglottic pressure reduction and phonatory incompetence resulting from the hypokinesia of the laryngeal musculature; or F0 can increase, under the effect of anti-Parkinsonian medication together with compensation strategies to optimize laryngeal closure; or F0 remains unchanged, by counterbalancing factors such as pitch elevation and lowering (Pinto, Ghio, Teston, & Viallet, 2010; Teston & Viallet, 2005; Viallet & Teston, 2007). In addition, recent studies suggest that F0 measures vary with the language of the speaker (*e.g.*, Pépiot, 2014).

A breathy and harsh voice, as found in PD dysarthria, is considered abnormal for patients whose spoken language does not involve such voice particularities. What about languages that use breathy vowels or modal and creaky tone? Such changes of voice quality, which can be induced by PD, might have a different impact on communication efficiency (Miller et al., 2014), and require some refinements and adaptations dependent on languages. Studies on dysphonia contributed to the view that dependent on the language the patient speaks, there are different impacts on production: spasms of the vocal folds vary as a function of the voiced or voiceless consonants, and dependent on the distribution of these types of consonants in the languages, the characterization of spasmodic dysphonia might differ (Lorch & Whurr, 2003). On the other hand, another cross-language study performed with Italian and French dysphonic patients concluded that perception of the overall grade of dysphonia and breathiness was not language-dependent (Ghio et al., 2015). Naturalness of voice/speech, a criterion used for example by Darley et al. for the classification of dysarthrias (Darley et al., 1969a, 1969b), is fully dependent on a language, and would be evaluated differently in a given language, independently from any pathological aspects. In other words, knowing about the variation-from-normal in various languages is of crucial importance to evaluate as precisely as possible any voice modulation that is acceptable in one language, and which could be identified as abnormal in another.

2.2. Articulation

Articulatory abnormalities in PD often concern the stop consonants, which can be produced and perceived as fricatives (Logemann & Fisher, 1981): instead of a silence during the closure phase of a plosive, normally expected due to the occlusion of the vocal tract, the acoustic signal displays a low intensity frictional noise due to the air passage. Fig. 1 illustrates this observation which is defined as the spirantization phenomenon (Ackermann & Ziegler, 1991; Kent & Rosenbek, 1982). This is probably the consequence of the hypo- and bradykinesia of articulatory organs, which are also subject to muscle stiffness. Analysis of direction and velocity of the articulatory organs, including lips and mandible, also tend to show a decrease in the range of motion and speed in PD patients (Svensson, Henningson, & Karlsson, 1993).

Regarding vowel production, there is a trend towards a reduction of the vowel space, which together with spirantization and coarticulation contributes to the reduction of phonetic contrasts of PD speech in its advanced stages (Tjaden, 2000). It has also been reported that some vowel metrics may be useful clinically for the detection of dysarthria (Lansford & Liss, 2014). One example is the European Portuguese pronunciation, which is characterized by assimilation (one sound becomes more like a nearby sound) and sandhi (*e.g.*, the fusion of sounds across word boundaries, and the alteration of sounds due to neighboring sounds or due to the grammatical function of adjacent words; Campbell, 2000). In fact, European Portuguese is a language with a rather lax articulation that reveals various phonetic modifications: many plosives

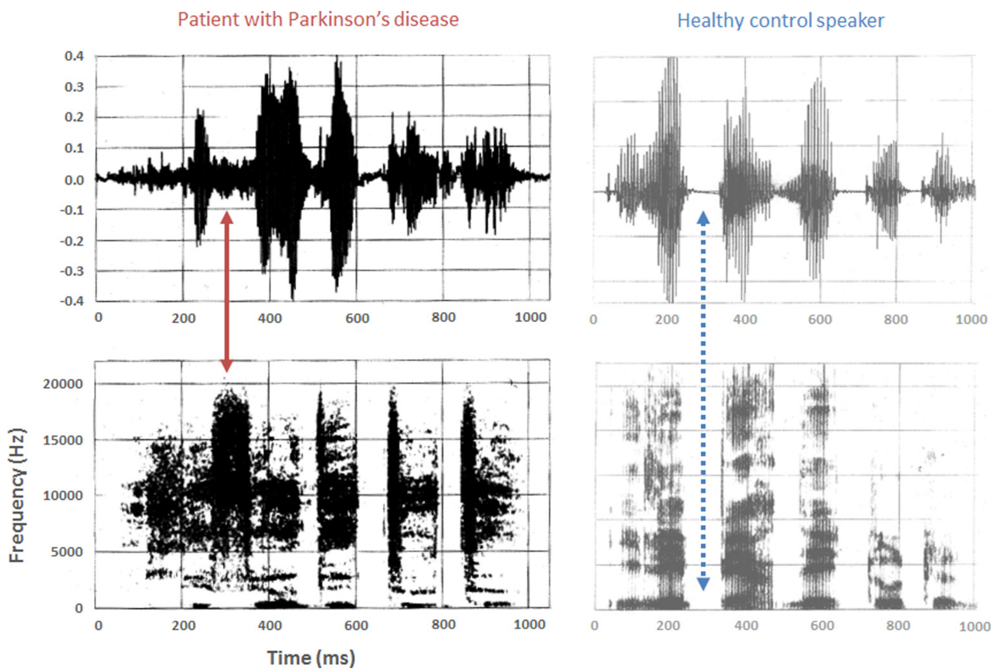

Fig. 1. Spirantization in PD speech (adapted from Robert & Spezza, 2005). On the left panel, in dark grey, a PD patient producing the French sentence 'il les perdait toutes' [he lost them all]: A frictional noise is observed and associated with an air passage due to an abnormal occlusion of the vocal tract during the stop consonant /p/ at the beginning of the verb 'perdait'. On the right panel, in light grey, a healthy speaker producing the same sentence: during the stop consonant /p/, a silence is visible in the spectrogram.

are spirantized and vowel articulation is often undershot. These two latter facts are quite characteristic of PD dysarthria as described in the literature and previously mentioned. What could be expected from a PD patient speaking European Portuguese? At least two possible expectations can be formulated: (1) patients' productions could be better preserved, since such modifications are part of the language and shared with interlocutors; or (2) degradation of patients' speech is amplified in European Portuguese when compared to other languages, because of the exacerbation of the spirantization and reduced vowel articulation. Further examples, such as the specific consonants involved in some African languages (clicks of the Khoisan languages, speech sounds of Semitic languages [pharyngeal, laryngeal, uvular and velar consonants] as in Arabic), should provide further important insights about the alteration of particular pharyngeal and velar deficits in PD dysarthria.

2.3. Prosody

Prosodic information, including intonation, tempo, stress and rhythm, serves many functions for the listener and speaker: it helps to segment the continuous flow of spoken language into words, groups these words into phrases for interpretation, and indicates the relative importance and function of the interpreted meanings (Frota, 2002a, 2014; Ladd, 1996; Welby, 2007). It is commonly accepted that prosody deficits are a perceptual hallmark of dysarthria, and as a consequence, it is important to further study dysprosody in order to provide assistance in differential diagnosis, designating severity, and determining the need and focus of treatment (Patel, 2011). Degradation of prosody may have crucial consequences for speech intelligibility and communication. As mentioned previously, perceptual and acoustic investigations of PD speech reported alterations of F0 (pitch), as part of a prosodic insufficiency. For example, in an ongoing study which compares the melodic curve of a French sentence pronounced by a group of healthy controls and PD patients, a flattened curve is observed in the case of female patient productions (Fig. 2). Also, the study of F0 distribution in PD patients indicated a loss of the upper part of the tonal range (Viallet, Meynadier, Lagrue, Mignard, & Gantcheva, 2000). In fact, the monotony of pitch results from the reduction of the dynamic frequency and the tonal range, which alter the prosody by reducing pitch contrasts between target points, whose structure remains preserved (Teston & Viallet, 2005). F0 was also found to differ between PD patients and control participants in the

Fig. 2. Melodic curve (normed F0, in Hz) measured in a sentence produced by healthy controls (in blue) and patients with PD (in red). All participants were female, French-native speakers. PD patients were unmedicated. The sentence produced was extracted from the paragraph 'The North wind and the Sun' (Fougeron & Smith, 1999). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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context of contrastive features and emotional prosody (Cheang & Pell, 2007). Besides, a decrease in loudness modulation, *i.e.*, monoloudness, is very often part of speech deficits in PD.

A study compared French and English prosody in control speakers and reported that 'Approximating a sentence's prosody by means of its F0 alone yields reasonably acceptable results in English because, in this particular language, duration and intensity tend to be strongly correlated with F0 (...) By contrast, in French, there are (at least) two positions within a polysyllabic word that have a potential for hosting an intonational morpheme' (Vaissière & Michaud, 2006, p. 57). Prosodic structure is to a large extent language-specific, and this is *de facto* of great importance in the context of speech disorders that lead to a loss of prosody. Up to now, only very few studies on PD dysprosody have looked beyond general measures, such as F0 modulations, to examine auto-segmental metrics that are linguistically important (*e.g.*, Pinto et al., 2016).

2.3.1. Intonation and tones

One aspect of prosody that has not been sufficiently addressed in the literature concerns PD speech in patients speaking tonal languages (Ma, Whitehill, & So, 2010; Whitehill, 2010). Cantonese offers an excellent opportunity to evaluate how speech breakdown in PD dysarthria may interact with the typological characteristics of the patients' language, due to its key feature of being a language with six contrastive tones that signal meaning differences (Matthews & Yip, 2011). There has only been very limited published work studying lexical tone production in Cantonese PD patients. Wong and Diehl (1999) examined the tone production of one Cantonese-speaking PD patient, and found that the patient had a more restricted pitch range and a smaller tonal space of the six lexical tones. This case-study limits generalization of the findings; besides, the patient was assessed only 15 months after diagnosis of the disease, and thus speech impairment resulting from PD may still be very mild. Whitehill, Ma, and Lee (2003) studied the perceptual speech features of 18 Cantonese speakers with hypokinetic dysarthria associated with PD. Interestingly, despite monopitch being recognized as severely affected, tone distortion was judged perceptually as relatively less affected. The authors suggested that the difference in the severity for tone distortion and monopitch raises the possibility of differential control for lexical tone and intonation (Vance, 1976). Despite this interesting finding, this study's focus on perceptual judgment may have missed out possible impairment in refined pitch control in lexical tone production, which is better revealed by acoustic analyses. Future research on tonal languages using a combination of perceptual and acoustic evaluations is needed.

Perceptually, we suggest tests of intelligibility and goodness of fit ratings by a larger number of listeners, to compare the intelligibility and quality of lexical tones produced by PD patients and healthy controls. Acoustically, we suggest measuring the F0 across the time course of the target syllable for PD patients and healthy controls. One can also compare the F0 range of the 'tone space' (defined as the distance between the maximal and minimal F0 values in production of the highest tone and lowest tone) in PD patients and normal controls. To do this, we suggest using words that are minimal pairs of tones as well as passages to study how lexical tone is realized and distorted at both word and sentence levels, bringing in multiple sources of variability. Ideally, the tone minimal pairs should contrast in all the six tones and cover different phonetic contexts (Zhang, Peng, & Wang, 2012). Future studies targeting PD patients at different disease stages and severity levels using cross-sectional and longitudinal designs could lead to a better understanding of the relationship between tone distortion and speech naturalness/intelligibility in PD speech.

Theoretically, studying tonal languages like Cantonese also allows testing two opposing hypotheses. One hypothesis in line with the linguistic-based account is that degradation of patients' speech intelligibility is exacerbated in Cantonese, because pitch contrasts that are relevant for distinguishing meanings in a tonal language may be lost. Thus, the prediction would be that there is a clear divide between the speech of patients and that of healthy controls. An alternative hypothesis in line with the disease-based account would be that since tone skills are acquired early and are highly practiced, they are less vulnerable to impairment. Thus the prediction would be that speech intelligibility of patients could be preserved and not compromised by reduced pitch variation, with little differences between patients and healthy controls. This finding would also support the dissociation of control for lexical tone and intonation skills. The field of dysarthria research needs further experimental designs comparing PD patients with healthy controls that explicitly test these two opposing hypotheses.

2.3.2. Intonation and stress

Although French and European Portuguese are both Romance languages, they differ prosodically in a number of ways. European Portuguese intonation implies that lexical stress is not restricted to one fixed syllabic position in all words: words may be stressed on one of the last three syllables, although the vast majority of words are stressed on the penultimate syllable (Cruz-Ferreira, 1998). European Portuguese has contrastive lexical stress: each content word (noun, adjective, verb, etc.) has one syllable that is particularly salient or stressed, and changing the position of the lexical stress can change the meaning of a word (Cruz-Ferreira, 1998, 1999; Frota, 2000, 2014, chap. 2). Stressed syllables may be accompanied by a pitch accent, realized as a modulation in F0 (*e.g.*, a rise or a fall) and aligned in language-specific ways with the syllable. By contrast, French is usually described as a language with fixed stress: a primary stress is regularly assigned to the final full syllable of the last lexical item of a stress group, and a second stress, non-final and optional, is more generally assigned to the first syllable of a content word (Di Cristo, 1998; Jun & Fougeron, 2002; Welby, 2006). The realization of such stress implies pitch prominence. Thus, French intonation is generally characterized by a F0 rise on the last syllable of a phrase that is not utterance final, and an optional early (initial) rise may occur somewhere before the late or final rise (Welby, 2006). Stress in French is therefore generally considered not to be a property of the word, but of a larger unit that includes one or more content words and any preceding function words (articles, prepositions, etc.). This unit is called differently depending on theories of prosodic organization in French (*e.g.*, 'intonème mineur', Delattre, 1966; Rossi, 1985, 1999; 'rhythmic unit', Di Cristo & Hirst, 1993; 'Phonological Phrase'

Delais-Roussarie, 1996; Féry, 2001; Post, 2000; 'accentual group', Mertens, 1993). Within the metrical theory of French intonation (Ladd, 1996; Pierrehumbert, 1980) the 'Accentual Phrase' is tonally defined as the basic unit of French intonation (Jun & Fougeron, 2000, 2002; Welby, 2006). The Accentual Phrase is defined by a typical pitch accent (LH*), which is non-final within the utterance. From a phonetic point of view, this pitch accent is realized as an F0 rise whose maximum is aligned with the last syllable of the phrase which is lengthened (for further information, see for example Michelas & D'Imperio, 2012). French listeners use these F0 rises as cues to word segmentation, finding the beginning and ends of words in the speech stream, and to lexical access, retrieving words from the mental lexicon (Spinelli, Grimault, Meunier, & Welby, 2010; Welby, 2007).

Such intonation differences across languages make the comparison of prosodic deficits in individuals with PD particularly interesting. Does a Portuguese patient experience different communication impairments when compared to a French patient? And if this is the case, is this difference related to the fact that European Portuguese stress is distinctive and varies in position? And finally, how do these intonational differences evolve in relation to the patients' disease duration and pharmacological treatment (Pinto et al., 2016)?

2.4. Speech rate and temporal organization

Language-specific breakdowns of rhythm have been suggested on the basis of empirical and theoretical reasons (Liss, Utianski, & Lansford, 2013), but conversely, it has also been reported that rhythm metrics do not differentiate healthy from dysarthric speech (Lowit, 2014). Even if some acceleration of articulation rate was reported in PD patients (Skodda & Schlegel, 2008), speech rate tends to be slower in PD than in healthy controls and seems to be correlated with a longer pause time; the average duration of pauses was found to be significantly longer in PD patients than in control participants, while the average length of sound sequences showed no significant difference between patients and controls (Duez, 2005; Hammen & Yorkston, 1996). On the other hand, it has been shown that PD patients made overall significantly fewer but longer pauses at the end of words and fewer pauses within polysyllabic words (Skodda & Schlegel, 2008). Notably, most patients tend to maintain the contrasting duration of consonants and vowels, suggesting that low-level constraints operate similarly and equally in PD and in healthy controls (Duez, 2009; Duez, Jankowski, Purson, & Viallet, 2012; Duez, Legou, & Viallet, 2009; Skodda & Schlegel, 2008). The findings on pause durations suggest that differential temporal organization in PD patients and healthy controls contribute to the degradation of speech intelligibility in PD. Although these existing studies employed different designs (number of patients, language, effects of treatment, etc.), they all used a disease-based approach, as they all tried to identify differences in PD patients when compared to controls.

Alteration of speech pauses and pace suggest impaired speech rhythm and timing organization (Skodda & Schlegel, 2008). The current opinion is that abnormalities in speech articulatory rate and regularity might serve as a marker of disease progression in PD (Skodda, 2011). Rhythmic activity, acting as an 'internal model', influences the temporal organization of speech production and may be involved in anomalies of duration phenomena (constrictions, vowels, syllabic nuclei, alternative rhythms). These may in turn affect prosodic performance and consequently intelligibility (Kent, Kent, Weismer, & Duffy, 2000). Also, tonal alignment is likely to be a relevant factor in the study of PD dysprosody since it relies on precise coordination of glottal and articulatory gestures to achieve language-specific temporal patterns for pitch accents and boundary tones. Thus, further research could analyze tonal alignment in the F0 curve, that is, the temporal coordination of high and low tones with specific syllables in the sentences (D'Imperio, 2011; Frota, 2002b; Welby & Lœvenbruck, 2006).

2.5. Speech intelligibility

Recall that we conceptualized the breakdown of speech motor control as a question of language constraints *vs.* dysarthria-induced production alterations. In fact, language-specific modifications (such as breathy vowels, elisions, coarticulations and collapses, lexical stress, etc.) could be considered as abnormal at the production level, but completely acceptable in terms of perception and thus intelligible. From a practical point of view, and with the objective of managing PD dysarthria in patients according to their specific language, speech intelligibility should be a measure systematically included in cross-language studies and assessed along with the dysarthria-induced production alterations. This is the case of current cross-linguistic studies on dysarthria (*e.g.*, Kim & Choi, 2016; Pinto et al., 2016), which aim at providing recommendations that integrate language-specific dimensions in behavioral speech therapy and management. How to evaluate speech intelligibility in PD? There are mainly three approaches:

First, as part of the clinical evaluation of the oromotor activity, speech intelligibility is evaluated by the speech and language pathologist who will use tools in order to assess intelligibility as a marker of dysarthria severity (*e.g.*, in English: Assessment of Intelligibility of Dysarthric Speech (Yorkston & Beukelman, 1981); Unpredictable sentences for intelligibility testing (McHenry & Parle, 2006); the intelligibility part of the Frenchay Dysarthria Assessment [version 1: Enderby, 1983; version 2: Enderby & Palmer, 2008]).These tools are often adapted and validated in different languages: *e.g.*, the Frenchay Dysarthria Assessment has been adapted into French (version 1, Auzou & Rolland-Monnoury, 2006) and European Portuguese (version 2, Cardoso et al., 2017). Such assessments mainly require the patients to read a small set of isolated words and/or short sentences (the global perception of speech deficit also involves the reading of a short text), which have to be rated by the speech and language pathologist. In this case, the speech and language pathologist is influenced by their own expertise about assessing speech impairment: the knowledge of the disease, the tool (more specifically, the stimuli), the patient, etc.

Second, some assessments use multiple-choice evaluations that provide descriptions of articulatory deficits. These tests are based on series of words and/or logatomes of variable length whose pronunciation might lead to different types of phonetic errors: omissions, substitutions, distortions, additions, repetitions. For example, this is the case for the Single Word Intelligibility Test (Kent, Weismer, Kent, & Rosenbek, 1989), also translated and adapted for example into French by Gentil (1992). These examinations describe the articulatory deficits from a phonetic point of view, but they do not reflect the severity degree of dysarthria and its impact on communication.

Third, as an extension to the evaluation of words and sentences used with the previously presented clinical tools, a further kind of evaluation could be proposed. When recording the productions of the patients, the words and sentences could be evaluated by a group of listeners composing an auditory jury rather than using only a single listener such as the speech and language pathologist. The auditory jury should be composed of native speakers of the language spoken by the patients, without any history of auditory and/or visual deficit, unfamiliar with speech modulations in neurodegenerative disease, and naïve with regard to the aim of the experiment. At the end of the evaluation, the percentage of correctly understood words or sentences would provide an indicator of speech intelligibility in a 'functional communication' context (*cf.* Pinto et al., 2014). On the other hand, this methodology is quite time-consuming, as raised by Stipancic, Tjaden, and Wilding (2016). In their study, the authors compared two kinds of intelligibility measures, *i.e.*, 'objective' orthographic transcription *vs.* 'subjective' estimation scaling (using a visual analog scaling – VAS). They reported that the patterns of descriptive and parametric statistics for both types of measures were similar, and that correlation analyses showed a moderately strong relationship between the two measures. They concluded that *'there may be instances when the less time-consuming VAS task may be a viable substitute for an orthographic transcription task when documenting intelligibility in mild dysarthria*' (Stipancic et al., 2016, p. 230). Subjective estimation scaling seems also to be sensitive to PD speech changes following treatment, such as neurostimulation (Atkinson-Clement et al., 2017).

It is important to remember that the assessment of speech intelligibility in PD patients refers to the perception of what has been understood from a listener's perspective (*e.g.*, carers, health professionals, speech and language pathologists). A commonly accepted bias is introduced by assessing the speech disorder as one motor sign among others, rather than an indicator of communication efficiency. Self-evaluation questionnaires are available to take into account the patient's point of view: for example, the Voice Handicap Index (Jacobson et al., 1997; Guimarães, Cardoso, Pinto, & Ferreira, 2017) is often considered a reference-standard for such evaluations. The recent development of self-questionnaires that provide the patients' own perspective of their speech disability and its impact on communication (*e.g.*, the Dysarthria Impact Profile; Letanneux, Viallet, Walshe, & Pinto, 2013; Walshe, Peach, & Miller, 2009) brings new and interesting tools that can help distinguishing symptom severity and communication impairment. Finally, speech intelligibility in PD, as all speech dimensions and measures previously mentioned, depends also on disease duration, disease severity, the patients themselves and their own pathophysiology and response to treatments.

2.6. Compensation mechanisms during speech breakdown in PD

As previously mentioned, an increase in F0 in PD patients could be seen as a compensation strategy to optimize laryngeal closure (Viallet & Teston, 2007). Furthermore, spirantization and lack of velopharyngeal closure (Kent & Netsell, 1971) could also result from a compensatory mechanism for articulatory deficits, avoiding specific movements and making others easier. Such compensatory strategies are expected to reflect cerebral pathomechanisms involved in Parkinsonian dysarthria. Neuroimaging studies (Liotti et al., 2003; Maillet et al., 2012; Narayana et al., 2009, 2010; Pinto et al., 2004, 2011; Rektorova, Barrett, Mikl, Rektor, & Paus, 2007; Rektorova et al., 2012; Sachin et al., 2008) reported that PD speech seems to be related to an altered recruitment of the main brain motor regions underlying speech production and an increased involvement of additional areas, suggesting that a specific reorganization underlies the altered activation pattern associated with PD speech. Following our theoretical framework, *i.e.*, from a disease-based point of view, one could argue that such compensatory brain mechanisms are implemented to preserve speech in PD and reflect specific adjustments that patients develop with the progression of the disease.

PD also involves a deficit of processing sensory information for the calibration of fine motor activities through 'internal models' that are used for performing movements (Kent et al., 2000). This interpretation is particularly suited to explain the volume reduction in the voice of PD patients despite the patients' perception of a normal volume (Ho, Bradshaw et al., 1999; Ho, Iansek et al., 1999), and is corroborated by findings related to specific hearing impairment in PD (Vitale et al., 2012). Recently, Arnold et al. (2014) summarized and highlighted three brain functional anomalies underlying pathomechanisms of PD speech: (1) a striato-prefontal hypoconnectivity and dysfunctional self-monitoring mechanisms, underpinning the diminished motor drive of hypophonia; (2) a reduced external auditory feedback that affects speech motor representations; and (3) a disturbed modulation of speech routines and affective prosody (Arnold et al., 2014). These modifications could reflect either compensatory mechanisms or modifications of the activation pattern underlying brain dysfunctions of PD speech. From a (neuro)linguistic-based perspective, these alterations of speech motor representations could then lead to different dysfunctions of perceptual deficits, which could also be language-specific.

3. Proof of concept and perspectives

A significant recommendation from the International Classification of Functioning Disability and Health (World Health Organisation, 2001) is to improve quality of healthcare and encouraging clinicians to adopt a more holistic approach to the assessment and treatment of patients. We believe that research in the field of speech sciences needs to incorporate this viewpoint when studying pathological speech. Thus, an ideal speech assessment should combine different tools, approaches, methods and kinds of evaluation in order to provide a thorough examination, as well as the possibility of elaborating interpretative tracks based upon the two approaches we defined previously: disease-based and (neuro)linguistic-based.

The few cross-linguistic studies conducted so far point to more similarities than differences in how dysarthria affects the speech and/or intelligibility of PD patients in different languages (*e.g.*, Chakraborty et al., 2008; Ghio et al., 2015; Orozco-Arroyave et al., 2016; Whitehill et al., 2003). As we outlined in the present opinion article, this assumption still has to be tested against a wide variety of languages and on several linguistic dimensions. A remaining issue is to determine how linguistically and culturally appropriate current models of diagnosis and treatment generalize to more diverse populations, such as bilingual or multilingual speakers. It is still unclear how the breakdown of motor speech control interacts with other languages beyond English and how these interactions may surface for example in speakers of multiple languages. As mentioned in the previous sections, several recent studies point to cross-linguistic differences in aspects such as phonation or prosody. For example, speakers of different languages use F0 values or intonation patterns that are specific to each language (*e.g.*, Pépiot, 2014). Would certain features of a first language be better maintained due to proficiency of another language in which these features are distinctive? In other words, can certain motor control skills of a second language be transferred to the first language and delay breakdown? Or is it necessary to have an overlap of linguistic attributes across language pairs in order to delay the occurrence of certain motor speech disorders in one language or the other? These kinds of questions are relevant since studies on bilingualism show that properties of each of the spoken languages influence the production of speech at several levels of processing (*e.g.*, Flege, 1987; Nip & Blumenfeld, 2015; Sadat, Martin, Magnuson, Alario, & Costa, 2016). Given the increase of population that is bi/multilingual and the diverse populations of patients seeking speech and language therapy, these are important questions that need to be addressed in future research. However, issues regarding speech motor control in bilingual speakers are complex in nature, and are often challenging to disentangle. This further justifies why it is important to first broaden the diversity of languages studied as groundwork to incorporate insights from linguistic typology into conceptualizing and managing dysarthria. This is the "language-diverse" view of dysarthria we are proposing in the current article.

Another important dimension when studying the breakdown of speech motor control is that there is more to speech perception than purely perceptual distinctiveness. Flattened intonation patterns are more likely to elicit emotions of indifference or disinterest in the speech of patients. This may lead to communication problems beyond simple acoustic deficits, and research on emotional prosody in PD dysarthria (Schröder, Nikolova, & Dengler, 2010) is one of the tracks that needs to be pursued. In addition, research has started to examine how dialectal differences within the same language can affect speech intelligibility of dysarthric speakers. For example, Dagenais and Stallworth (2014) explored dialectal differences in the dysarthric speech of African American and Caucasian Americans and found that perceptual raters tended to give higher ratings to speakers of their own ethnicity. There is clearly a need to consider also the role of cultural identity in our understanding of dysarthria.

Speech impairment in PD is a complex performance, which degenerates progressively with time, dependent on progressive neuronal loss, mechanisms of compensation, effects and side-effects of treatments (with transient duration, like with medication, or with potential longer neuroplastic reorganizations, such as speech therapy and other behavioral strategies), concomitant pathologies, etc. All these parameters contribute in various proportions to Parkinsonian speech and shape dysarthria over time: PD speech changes from one hour to the other, from one week to the next, and worsens slowly over the years. Accordingly, patients could be followed-up over time in order to capture the rich variations as the disease progresses. So would it be relevant to consider the study of dysarthria, and particularly in PD, in the framework of a dynamic system? As we mentioned above, dysarthria represents *per se* a dynamical model of progressive speech alteration. Considering that *'[systems]' behavior is best studied in terms of change over time*' (Mücke, Grice, & Cho, 2014, p. 2), it seems reasonable to argue that a dynamical approach is particularly suitable to study the temporal organization of speech output in dysarthria. Speech being conceptualized as a non-linear dynamical system, without any hierarchical structure over motor control, is a core foundational concept in the development of dynamical speech models such as Task Dynamics (*e.g.*, Saltzman, 1991; Saltzman & Kelso, 1987; Saltzman & Munhall, 1989) and its implementation in Articulatory Phonology (*e.g.*, Browman & Goldstein, 1992) or Embodied Task Dynamics (Šimko & Cummins, 2010), and even the Selection-Coordination theory (Tilsen, 2016), an extension of Articulatory Phonology. The Task Dynamics model in speech production '*represents an attempt to reconcile the linguistic hypothesis that speech involves an underlying sequencing of abstract, context-independent units, with the empirical observation of context-dependent interleaving of articulatory movements'* (Browman & Goldstein, 1992, p. 23). For dysarthric speech, such as in PD, articulatory, phonological and various other voice/speech disorders mentioned above converge into a pathological state that involves particularities of both the disease (and notably its worsening over time) and the target spoken language. Such a dynamic framework could provide fruitful insights that could illuminate dynamical underpinnings of speech impairment in PD, which may also vary across languages. Further investigation of PD speech could benefit from using dynamical frameworks, especially with respect to cross-linguistic variations in gestural coordination patterns (*e.g.*, coordination of word initial consonant clusters differing across languages; *cf*. Hermes, Mücke, & Auris, 2017, this volume), and for that purpose, the direct investigation of the articulators (*e.g.*, using Ultrasound or EMA) could be a relevant option.

4. Conclusion

Studying the pathological state of speech and its interaction with specific languages has the potential to not only inform our understanding of normal speech functioning, but also refine current models of speech motor control and broaden our expectations of motor speech disorders.

The two approaches that we defined in the current article as disease-based and (neuro)linguistic-based are complementary and necessary for further guidance. After all, '*pathology is no more than a branch, a result, a complement of physiology, or rather, physiology embraces the study of vital actions at all stages of the existence of living things. [...] Physiology and pathology clarify each other*' (Begin, 1821; in Canguilhem, 1943).

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