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Towards an automatic evaluation of the dysarthria level of patients with Parkinson's disease

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ABSTRACT

Background: Parkinson's disease (PD) is a neurological disorder that produces motor and non-motor impairments. The evaluation of motor symptoms is currently performed following the third section of the Movement Disorder Society – Unified Parkinson's Disease Rating Scale (MDS-UPDRS-III); however, only one item of that scale is related to speech impairments. It is necessary to develop a specific scale such that considers those aspects related to speech impairments of the patients.

Aims: (i) To introduce and evaluate the suitability of a modified version of the Frenchay Dysarthria Assessment (m-FDA) scale to quantify the dysarthria level of PD patients; (ii) to objectively model dysarthric speech signals considering four speech dimensions; (iii) to develop a methodology, based on speech processing and machine learning methods, to automatically quantify/predict the dysarthria level of patients with PD.

Methods: The speech recordings are modeled using features extracted from several dimensions of speech: phonation, articulation, prosody, and intelligibility. The dysarthria level is quantified using linear and non-linear regression models. Speaker models based on i-vectors are also explored.

Results and conclusions: The m-FDA scale was introduced to assess the dysarthria level of patients with PD. Articulation features extracted from continuous speech signals to create i-vectors were the most accurate to quantify the dysarthria level, with correlations of up to 0.69 between the predicted m-FDA scores and those assigned by the phoniatricians. When the dysarthria levels were estimated considering dedicated speech exercises such as rapid repetition of syllables (DDKs) and read texts, the correlations were 0.64 and 0.57, respectively. In addition, the combination of several feature sets and speech tasks improved the results, which validates the hypothesis about the contribution of information from different tasks and feature sets when assessing dysarthric speech signals. The speaker models seem to be promising to perform individual modeling for monitoring the dysarthria level of PD patients. The proposed approach may help clinicians to make more accurate and timely decisions about the evaluation and therapy associated to the dysarthria level of patients. The proposed approach is a great step towards unobtrusive/ecological evaluations of patients with dysarthric speech without the need of attending medical appointments.

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1. Introduction

Parkinson's disease (PD) is a neurological disorder characterized by the progressive loss of dopaminergic neurons in the midbrain, producing several motor and non-motor impairments (Hornykiewicz, 1998). Motor symptoms include, bradykinesia, rigidity, resting tremor, micrographia, and different speech impairments. The disease progression in motor activities is currently evaluated with the third section of the Movement Disorder Society – Unified Parkinson's Disease Rating Scale (MDS-UPDRS-III) (Goetz, 2008). This section comprises 33 items and is administered by neurologist experts according to their own clinical criterion. Thus it could be highly subjective. The scale contains several items to evaluate different motor activities such as finger tapping, gait, speech, and facial expression. Although the majority of PD patients develop several speech disorders, only one item in the scale is related to speech (Logemann, Fisher, Boshes, & Blonsky, 1978). Those disorders are considered an early sign of further motor impairments (Hlavnicka et al., 2017; Rusz et al., 2013). The most common symptoms in the speech of PD patients include reduced loudness, monopitch, monoloudness, reduced stress, breathy, hoarse voice quality, and imprecise articulation. These impairments are grouped together and called *hypokinetic dysarthria* (Logemann et al., 1978).

Although the MDS-UPDRS-III evaluates motor skills including the movement of hands and arms, gait, and posture, among others, it is not suitable nor fair to assume that the scale can be accurately predicted only based on speech recordings. To evaluate the impact of PD on an aspect of communication, a scale for evaluating speech would be a valuable tool. Several studies have considered the application of scales to assess only the speech deficits of PD patients (Patel, Parveen, & Anand, 2016; Skodda, Visser, & Schlegel, 2011). For instance, the Frenchay Dysarthria Assessment (FDA) introduced by Enderby (1980) and revised by Enderby and Palmer (2008) was designed to assess dysarthria, which is also suffered by PD patients. The FDA scale includes several items to evaluate dysarthria such as reflexes, respiration, lips movement, palate movement, laryngeal capacity, tongue posture/movement, intelligibility, and others. This tool covers a wide range of aspects; however, it requires the patient to be with the examiner, which is not possible in many cases due to their reduced mobility.

The research community has addressed since several years the problem of reducing the subjectivity of clinical evaluations to guarantee their reproducibility. The main purpose is to provide additional information to the clinical expert to reduce subjectivity in the final diagnosis. For the specific case of pathological speech analysis, researchers work on two main aspects: the development of suitable and accurate acoustic measures to model the speech signals and the development of different signal processing and machine learning techniques to reduce the subjectivity in clinical evaluations, e.g., trying to predict the score of a scale. With the aim of contributing to these two challenges, this study introduces an objective and reproducible methodology to model speech signals and to quantify the dysarthria level of PD patients.

Several studies in the literature described the speech impairments of PD patients in terms of different dimensions such as phonation, articulation, prosody, and intelligibility (Orozco-Arroyave, 2016; Rusz, Cmejla, Ruzickova, & Ruzicka, 2011). Related studies describing the assessment of PD using each speech dimension are reviewed below and the features used to assess each dimension are described in Section 2.2.

1.1. Phonation analysis

Phonation in PD patients is characterized by bowing and inadequate closure of vocal folds (Hanson, Gerratt, & Ward, 1984), which produce problems in stability and periodicity of the vibration. Phonation in PD was analyzed by Tsanas, Little, Fox, and Ramig (2014), who used features related to perturbation, noise content, and non-linear dynamics to evaluate the response of 14 PD patients to the Lee Silverman voice treatment as “acceptable” or “unacceptable”. The authors considered only information from the sustained vowel /a/, and reported accuracies close to 90% discriminating between “acceptable” vs. “unacceptable” utterances. Orozco-Arroyave et al. (2015) evaluated different characterization methods related to phonation analysis for the classification of PD patients and healthy control (HC) speakers. The authors used information of sustained vowels and evaluated four different characterization approaches: stability and periodicity, noise measures, spectral wealth, and non-linear dynamics. They reported accuracies of up to 84%, depending on the analyzed vowel and on the feature set. Recently, Hemmerling, Orozco-Arroyave, Skalski, Gajda, and Nöth (2016) proposed a novel phonatory analysis in PD patients based on the Hilbert-Huang transformation computed upon modulated (varying between low and high pitch) and sustained vowels. The authors analyzed the fundamental frequency and its range to assess monotonicity in PD speakers. The authors automatically discriminated PD and HC speakers and reported accuracies of up to 90%.

1.2. Articulation analysis

Articulation deficits in PD patients are mainly related to reduced amplitude and velocity of lip, tongue, and jaw movements (Ackermann & Ziegler, 1991). It has been studied in several works, for instance Skodda, Visser, et al. (2011) evaluated possible correlations between vowel articulation, global motor performance, and the stage of the disease. The data considered by the authors included speech recordings of 68 patients and 32 HC. The authors concluded that the vowel articulation index is significantly reduced in PD speakers. Novotný, Rusz, Čmejla, and Růžička (2014) modeled six different articulatory deficits in PD: vowel quality, coordination of laryngeal and supra-laryngeal activity, precision of consonant articulation, tongue movement, occlusion weakening, and speech timing. The authors studied the rapid repetition of the syllables /pa-ta-ka/ pronounced by 24 Czech native speakers, and reported 88% accuracy discriminating between PD patients and HC speakers. Recently, Orozco-Arroyave (2016) proposed a method to model the difficulty of PD patients to start/stop the vocal fold vibration in continuous speech based on the energy content in the transitions from unvoiced to voiced and from voiced to unvoiced segments. The author addressed the automatic classification of PD