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Estimating bradykinesia severity in Parkinson's disease by analysing gait through a waist-worn sensor

A. Samà[a,c,*,1], C. Pérez-López[a,c,1], D. Rodríguez-Martín[a], A. Català[a,c], J.M. Moreno-Aróstegui[a,c], J. Cabestany[a,c], E. de Mingo[b], A. Rodríguez-Molinero[b,c]

[a] Technical Research Centre for the Dependency Care and Autonomous Living (CETpD), Universitat Politècnica de Catalunya – BarcelonaTech (UPC), Spain
[b] Clinical Research Unit, Consorci Sanitari del Garraf (Fundació Privada Sant Antoni Abat), Spain
[c] Sense4Care, Spain

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ABSTRACT

Bradykinesia is a cardinal symptom of Parkinson's disease (PD) and describes the slowness of movement revealed in patients. Current PD therapies are based on dopamine replacement, and given that bradykinesia is the symptom that best correlates with the dopaminergic deficiency, the knowledge of its fluctuations may be useful in the diagnosis, treatment and better understanding of the disease progression. This paper evaluates a machine learning method that analyses the signals provided by a triaxial accelerometer placed on the waist of PD patients in order to automatically assess bradykinetic gait unobtrusively. This method employs Support Vector Machines to determine those parts of the signals corresponding to gait. The frequency content of strides is then used to determine bradykinetic walking bouts and to estimate bradykinesia severity based on an epsilon-Support Vector Regression model. The method is validated in 12 PD patients, which leads to two main conclusions. Firstly, the frequency content of the strides allows for the dichotomic detection of bradykinesia with an accuracy higher than 90%. This process requires the use of a patient-dependant threshold that is estimated based on a leave-one-patient-out regression model. Secondly, bradykinesia severity measured through UPDRS scores is approximated by means of a regression model with errors below 10%. Although the method has to be further validated in more patients, results obtained suggest that the presented approach can be successfully used to rate bradykinesia in the daily life of PD patients unobtrusively.

1. Introduction

Parkinson's disease (PD) pathology is typified by the death of the dopamine-producing neurones, being dopamine a neurotransmitter required for a correct movement control [1]. The first noticeable PD signs correspond to an affected regulation of movement, and they are due to the said lack of dopamine-producing cells. This way, current PD treatments are based on increasing dopamine levels, being levodopa the most extended one. Although this active ingredient temporally reverts the symptoms, it does not prevent disease progression. Bradykinesia is one of the most incapacitating PD motor symptoms, and it is used to describe the pathological slowness of movement [2]. In addition to this, it is the main symptom related to basal ganglia disorders and, although it is a cardinal symptom of PD, it might also be present in other disorders, e.g. depression [1]. Bradykinesia is sometimes also used to describe two other motor disorders: akinesia and hypokinesia. Akinesia is related with a poverty of spontaneous movement, while hypokinesia describes decreased bodily movements [1]. In this article, we use bradykinesia to refer to those difficulties with planning, initiating and executing movement and with performing sequential and simultaneous tasks [1,2]. Although the pathophysiology of bradykinesia is not well known, it has been shown that, in patients with PD, bradykinesia is the symptom that best correlates with dopaminergic deficiency [3].

In current clinical practice, the assessment of bradykinesia includes the execution of rapid, repetitive, alternating movements of the hand and heel tapping while the clinician observes the slowness and amplitude of the movements [1]. This kind of assessment is employed in the Unified Parkinson's Disease Rating Scale (UPDRS), which is a clinical tool widely utilised by neurologists to evaluate different aspects

* Corresponding author at: Technical Research Centre for the Dependency Care and Autonomous Living (CETpD), Universitat Politècnica de Catalunya – BarcelonaTech (UPC), Spain
E-mail addresses: albert.sama@upc.edu (A. Samà), carlos.perez-lopez@upc.edu (C. Pérez-López), daniel.rodriguez-martin@upc.edu (D. Rodríguez-Martín), andreu.catala@upc.edu (A. Català), joan.manuel.moreno@upc.edu (J.M. Moreno-Aróstegui), joan.cabestany@upc.edu (J. Cabestany), itzahe1@hotmail.com (E. de Mingo), rodriguez.molinero@gmail.com (A. Rodríguez-Molinero).
[1] These authors contributed equally.

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of PD. UPDRS is a questionnaire divided into 4 parts: non-motor aspects, motor aspects, motor examination and motor complications; each part comprises several items that are rated with a score between 0 and 4. The third part of the UPDRS assesses the motor signs of PD as a patient manifests them at the moment of the assessment, being bradykinesia evaluated through several items in this third part. However, as explained above, bradykinesia is a symptom that can appear and disappear throughout the day and its presence and severity vary, among others, with the moment and quantity of the last medication intake and the punctual absorption response of the patient. Furthermore, the severity of this symptom also depends on the emotional state of the patient and the environment [1]. Thus, given that UPDRS is a punctual assessment, it does not show, in general, the real severity of the bradykinesia. In addition to this, the administration of UPDRS is very time-consuming for therapists, and the repeated administration of the scale is frustrating for patients since they have to repeat specific movements several times to re-evaluate their condition. Thus, the use of the UPDRS items in the evaluation of bradykinesia is burdensome and may provide biased information from the true scope of the symptom.

Novel signal processing methods and wearable devices have been recently developed to assess specific items of the UPDRS automatically, therefore enabling its evaluation at patients' home as in [4,5]. However, their usage is restricted to few times a day, since they require patients to perform specific exercises. In consequence, a system able to assess the onset of bradykinesia and its severity during patients' activities of daily living (ADL), without requiring to perform specific exercises, would be of great help in clinical practice. Given the correlation between bradykinesia and dopamine levels, the use of such systems would enable doctors to enhance the tailoring of the medication intakes and, therefore, improve the response to treatment. Additionally, the knowledge of the bradykinesia evolution may be a good indicator of the disease advance for neurologists. Finally, in patients with continuous infusion pump treatments, determining bradykinetic periods in real-time could open the possibility to automatically administrate rescue doses or bolus in order to avoid OFF periods.

This work presents a new machine learning method to assess and quantify bradykinesia by means of a single waist-worn accelerometer. The method is based on a Support Vector Machine (SVM) classifier that detects gait, a specific signal processing method that detects strides and, finally, a characterisation of these strides based on their frequency content. The resulting frequency characterisation is then entered into a regression method to estimate bradykinesia severity in terms of UPDRS scores. The device and method were tested with signals recorded from 12 PD patients while performing a set of scripted ADL at home. The method presented in this paper shows that an accurate monitoring of bradykinesia can be obtained from patients' gait through a single waist-worn device, with an average accuracy above 90%. Furthermore, results show that the method's output is highly correlated with UPDRS scores (correlation coefficient $r > 0.9$). Finally, bradykinesia-related items of the UPDRS are approximated by an epsilon-Support Vector Regression (ε − SVR) providing errors below 10% in some cases.

The paper is organised as follows. The next section presents several studies in which bradykinesia was assessed based on wearable sensors. Section 3 is devoted to describing the signal processing and machine learning approach to analyse bradykinesia. Section 4 describes the data collection with PD patients and the data analysis. Finally, results, discussion, and conclusions are detailed.

2. Related work

The research conducted so far on the detection of bradykinesia by means of inertial sensors is mainly based on characterising patients' movements, which was followed by one of the first works conducted in this field by Dunnewold et al. [6]. This study used ambulatory monitoring to quantify bradykinesia and hypokinesia in a population of 50 PD patients. To this end, two wrist-worn accelerometers were used. Results demonstrated limited sensitivity, around 60–71% and specificity of 66–76% in individual PD patients. Furthermore, the objective measures of bradykinesia in this study did not show any relationship with the score of the UPDRS.

Researchers at the École Polytechnique Fédérale de Lausanne evaluated the use 7 gyroscopes and 2 accelerometers located on the forearms, shins, and trunk to represent the presence or absence of tremor, bradykinesia, postural transitions, body posture and gait parameters [7]. The results showed correlations up to 0.71 with the bradykinesia UPDRS scores. Following this work, Salarian et al. used a wrist sensor to detect tremor and extract parameters related to bradykinesia in 20 PD patients [8]. Bradykinesia was measured in periods during which the patient moved the upper extremities. The estimated values were compared to the summation of specific UPDRS items, while Pearson's correlation was used between UPDRS subscores and the 3 parameters, showing values between −0.42 to −0.76.

Zwartjes et al. assessed bradykinesia and hypokinesia in PD patients while they were asked to perform certain daily tasks and UPDRS motor tests in a randomly predefined order [9]. Motor activity was measured using four inertial sensors placed on the trunk and wrist, thigh and foot of the most affected side of patients. Bradykinesia was characterised by the average value of acceleration, step length and step velocity, and other parameters. Hypokinesia parameters were characterised as how patients moved their arms. As these parameters cannot directly be translated into single UPDRS items, authors chose to compare them to the item that represents the overall bradykinesia and hypokinesia. None of the hypokinesia-related parameters was significantly correlated with this UPDRS item.

Recently, a study originated from a European research project called PERFORM was published by Cancela et al. [10]. In this paper, the authors presented a motor symptom monitoring system that was evaluated on twenty patients performing a scripted set of ADL. Several classification algorithms were tested, being SVM the one with the highest accuracy. In their paper, the algorithms assessed both the presence and severity of bradykinesia. Later, a modified version this algorithm was developed on the basis of inertial signals collected from 24 patients performing unscripted activities at their homes [11]. Results showed an accuracy of 74.4 ± 14.9% in detecting bradykinesia UPDRS scores. Nevertheless, in both cases, the system is composed of a set of five wearable sensors and a central store unit making the system unusable as a continuous monitoring for assessing ADL.

A wrist-worn sensor called Kinetigraph has also been evaluated in the automatic assessment of bradykinesia [12]. This device employs a triaxial accelerometer and analyses the frequency content within the bands of 0.2–4 Hz in order to produce bradykinesia scores every two minutes. These scores were compared to UPDRS part III rating values. The correlation coefficient among them was 0.64. The only error measurement that we could find in this paper states that Kinetigraph bradykinesia scores provided a margin of error of 18 UPDRS III units.

A distinct tendency of the evaluation of bradykinesia in PD involves scoring patient's response to some exercises, similarly to the evaluation of the UPDRS, based on the signals provided by specific sensors. For instance, Kim et al. [13] used a gyroscope to characterise the velocity and amplitude of finger tapping exercises. These characteristics show a correlation of 0.75 with UPDRS scores related to the tap test. In the same way, Dai el al. [14], in a recent article published in 2015 in which nine PD patients participated, obtained correlations up to 0.83 between the UPDRS bradykinesia score and measurements extracted from the finger tap test. Similarly, Kinesia device, which was developed by Great Lakes Neurotechnology, consists of a triaxial accelerometer and a gyroscope which analyses the movement of patient's finger [15]. Finally, eight sensors were employed by researchers from Harvard Medical School to estimate UPDRS score during scripted movement exercises [5]. These methods have the disadvantage of requiring