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Machine learning-based classification of simple drawing movements in Parkinson's disease

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ABSTRACT

This work explores the use of a pen-and-tablet device to study differences in hand movement and muscle coordination between healthy subjects and Parkinson's disease patients. We let volunteers draw simple horizontal lines and recorded the trajectory of the pen's tip on the pad's surface. The signals thus obtained were then processed to compute various features which correspond to the variability of the pen tip's velocity, the deviation from the horizontal plane, and the trajectory's entropy. Our goal was to establish simple and objective metrics which can be used to differentiate between normal and pathological movement. In a small-scale clinical trial, 44 age-matched subjects were divided in two groups, namely 20 healthy subjects (H), and 24 Parkinson's disease (PD) patients. We applied a comprehensive machine learning approach to build a model that could classify unknown subjects based on their line-drawing performance. We were able to achieve an average prediction accuracy of 91% (88% sensitivity [TP], 95% specificity [TN]). Our results show that the proposed method is a good candidate for differentiating between healthy and Parkinson's disease individuals, and shows promise in the context of telemedicine applications and tracking of the disease's symptoms via inexpensive, widely available hardware.

1. Introduction

PARKINSON's disease (PD) is one of the most representative and frequently encountered movement disorders; it is a neurodegenerative disorder with initial clinical features caused predominately by the loss of dopaminergic function in the substantia nigra pars compacta in the midbrain. PD is the second most common neurodegenerative disorder after Alzheimer's disease, and affects more than 1% of individuals over 55 and more than 3% of those over 75 years of age [1]. The cardinal features establishing a PD diagnosis are bradykinesia, tremor, rigidity and postural instability [2]. The disease includes non-motor symptoms as well which are not addressed directly in this study. The evaluation of patients' clinical status and response to medication is currently achieved via clinical assessment (neurological examination, clinical assessment scales). The careful application of diagnostic criteria, such as tremor, bradykinesia and rigidity derived from existing clinicopathologic studies can increase the positive predictive value of diagnosis to over 95% [3]. Nevertheless, a purely clinical assessment of the disease is inevitably a subjective procedure, and although additional factors can be used to increase the certainty of diagnosis, maximizing the specificity of the criteria leads to a significant decrease in the sensitivity of the diagnosis, sometimes excluding as many as one-third of "true" cases [4].

These considerations have led to various efforts aimed at quantifying aspects of the motor system and its disorders. The primary laboratory method used for the evaluation of motor disorders (including PD) is EMG, which involves recording the electrical activity of muscle fibers [5]. However, over the last few years, there has been a significant volume of research on alternative, simpler and user-friendlier devices used to measure aspects of movement disorders. One prominent example involves small-sized accelerometers [6–8], which are mounted on the patient's limbs and record during rest or while the patient executes a specified movement. Accelerometers have not yet transitioned into clinical practice; however, their widespread availability, in most smartphones, has led to increased research activity in that area (e.g., see Ref. [9] and references within).

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Other hardware used for the evaluation of motor disorders includes electronic tablet devices. They are inexpensive and do not require expertise in order to use. In Ref. [10] the authors used spectral analysis to identify PD tremor expressed as moment-to-moment fluctuations in the pen's position during a shape-tracing task. In Ref. [11] the hypometria and bradykinesia of PD patients was identified mainly during writing tasks with longer strokes. Aiming movements were performed on a digitizer tablet by the authors of Ref. [12], where it is shown that the decay in PD patients' positional sense affects the motor planning process. In Ref. [13], dopamine depletion in PD was found to affect sensorimotor adaptation.

The authors of Ref. [14] showed that spatial and temporal characteristics extracted from predefined handwritten text strokes can objectively discriminate between PD patients and healthy individuals; a later study [15] came to solidify those results, comparing results from micrographia (the abnormal reduction in the size of written text, associated with PD patients) versus spatiotemporal and kinematic variables extracted from digitized handwriting, defined generally as dysgraphia. The authors of Ref. [15] argue that with the advent of graphic tablets researchers should focus even more on dysgraphia, which pertains to all handwriting deficits characterizing PD, not only on the traditional measure of writing size. In other studies [16,17] pressure and in-air trajectory during handwriting are proven to be good potential markers for PD binary classification.

Writing is a skill that is developing later in a child's life. It involves a complex feedback system, integrating continuous information from the writing hand, i.e., proprioceptive sensory stimuli from all muscles involved, and sensory information from the fingers and the visual system. Also, writing is a task that implicates the participation of various degrees of cognitive processes. For this reason the majority of the related papers used tasks such as the Archimedes spiral [18], single letters or simple words, in order to investigate purely motor aspects of handwriting. The work in Ref. [19] took a different approach and showed that simpler tasks, namely drawing point-to-point trajectories, contained useful features that helped detect motor blocks in PD patients.

This paper's contribution is two-fold. First, we explore the use of a simple line-drawing task for classifying PD subjects using machine learning techniques with good results in terms of classification accuracy. The task in question is simpler than, for example, writing or drawing spirals, lasts only a few seconds, involves fewer muscular systems, no cognitive effort, and low coordination control effort. As it turns out, it is also unaffected by the dexterity of the participant's dominant hand, making it easy to perform using either hand, something which is not true in the case of writing letters or words. Second, our classification model is aided by the introduction of a new metric that characterizes the variability of the subject's drawing velocity and which, as we will see, is "rich" in information, more so than other "standard" markers that have been used in similar studies.

More specifically, we investigate the kinematics of hand motion during line drawing task, measuring hand movement at a timescale where there is no conscious control of the motion, so that what we detect is the balance of the tone of agonist versus antagonist muscular systems. This balance is altered in Parkinson's disease and in other pathological conditions. Unlike other studies on the subject, we aimed to make the task as simple as possible for the participants, and thus had them draw simple horizontal lines, hypothesizing that any imbalance in agonist-antagonist coordination should be present even in simple drawings. Our results validate that hypothesis, as we shall see. Furthermore, with lines, participants can draw starting from either side of the writing surface, extending or flexing their arms, allowing us to check the performance of two different groups of muscular systems.

Table I
Information for the Subjects' Age & Grouping.

Group (according to health & age)	Group size	Age Statistics	
		Mean ± StDev	StError
YH	15	36.40 ± 5.94	1.53
H	20	66.35 ± 7.91	1.61
PD	24	70.91 ± 5.74	1.17
Total	59		

Our hypothesis is that due to impaired coordination in patients with movement disorders, certain features, such as the velocity variability of the pen's tip (to be made precise shortly) or the "excursions" from the horizontal, should be more pronounced compared to healthy subjects. Towards that end, our approach involves recording the position of the pen on the tablet and computing a vector of metrics, namely the Normalized Velocity Variability (NVV), the velocity's Standard Deviation (SDV) and Mean (MV), and the signal Entropy (ETP), to characterize the pen's trace spatiotemporally. Using data acquired from healthy and PD individuals, we test the hypothesis that these metrics are statistically different between the two groups. Our hypothesis is based on research proving that velocity- and acceleration-based metrics of voluntary movements can separate pathological from healthy subjects. This includes Ref. [11] where PD patients showed a reduced ability to modulate acceleration, leading to smaller than required movements and micrographia, and Ref. [20] which showed that dopamine depletion in PD leads to smaller than normal pallidothalamic gating signals, which in turn affect the ability to control variable movement speed. The variability in handwriting velocity in patients with PD was also noted in Ref. [21] where the patients showed multiple peaks in their velocity signal whereas the controls showed just one peak. In Ref. [22], the velocity and acceleration profiles of PD patients were different in relation to healthy subjects while writing circles. In a different experimental design investigating the effect of the dopamine on handwriting movements [23], researchers found lower values for maximum and minimum velocity in ascending and descending strokes in PD patients than in healthy subjects. They also found that patients had significantly more inversions of velocity and acceleration than healthy people. There was also a difference between patients on medication and off medication, where the number of inversions in velocity and acceleration was statistically significant.

The remainder of this paper is organized as follows: In Section 2 we describe our experimental setup. In Section 3 we present the data analysis and introduce a machine learning model for classifying subjects. We conclude our paper in Section 4.

2. Experimental setup

2.1. Subjects

Fifty-nine subjects in total participated in this study. All were right-handed, and had normal or corrected-to-normal vision. Their right-handedness was established based on what hand they used to write and eat with, as well as an evaluation of the muscular force of their two hands. The subjects agreed to participate in this study after a detailed explanation of its purposes and procedures. They were divided in three groups based on their health status and age (Table I).

Group H included 20 healthy persons aged 56–89. All subjects had a detailed neurological examination in order to screen for any movement disorders that would exclude them from the study. None had a first-degree relative with PD or some kind of tremor.