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Full Length Research Paper

Classification of handwriting patterns in patients with Parkinson´s disease, using a biometric sensor

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Parkinson disease (PD) is characterized by typical movement disorders, important for clinical diagnosis and management. Objective assessment may be possible by mathematic classification of characteristics extracted by a sensor BiSP (Biosensor smart pen). The study aim to analyze handwriting characteristics of PD patients using a biosensor, and to classify the results by SVM-Support Vector Machines. 36 PD patients (group I) and 48 healthy adults (control group) with similar demographic characteristics were included. All realized drawing of patterned figures (spirals and meander) and tested diadochokinesia (pronation-supination test), using the BiSP pen. Biometric data were obtained from pen pressure, finger pressure on pen tip, acceleration of the movement, dislocation, tremor and instability. For each sensor were extracted characteristic features. Classification was tested using 70% of the data for learning and 30% for testing for each group, using the mathematic model of support vector machines. Accuracy of correct classification for each group and figure was described. For each figure, 8 to 12 features were extracted and submitted to SVM classification. Correct classification of PD patients and controls showed an accuracy of 96.7% for spirals, 95.4% for meander, 92.5% for diadochokinesia of the dominant hand and 93.6% diadochokinesia of the non-dominant hand. Combination of three figures, meander, spirales and diadochokinesia resulted in 99.6% of correct classification. The biometric features obtained by the BiSP permitted a correct classification of PD patients and control, using SMV as the mathematic tool. Biometrics and applied mathematics may help in PD characterization and follow- up.

Keywords: Parkinson´s disease, biosensor, mathematic classification, SV

INTRODUCTION

Parkinson´s disease (PD) is a chronic degenerative disease characterized by the loss of dopaminergic neurons of the *pars compacta* of the *substancianigra* of the mesencephalus. Its incidence is estimated in 3% of the population elder than 65 years, but with increasing prevalence when getting older.Atrophy and degeneration

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of the nuclei of the base are responsible for its typical motor disorders, as asymmetric tremor at a frequency at 4 to 7 HZ, bradykinesia, stiffness, freezing, besides others (Hoehn and Yahr, 1967; Savitt et al., 2006; Brusse et al., 2005; Barbosa et al., 2006).

Clinical evaluation of the tremor and bradykinesiais important for diagnosis, severity classification and status of pharmacological control of PD and actually a visual scale like the UPDRS (*Unified Parkinson Disease Rating Scale*) is being widely used (Siderow et al., 2002). Also, handwriting has been assessed as an objective measurement for PD characterization. The typicall form is known as micrographia (McLennan et al., 1992; Eichhorn et al., 1996; Conteras-Vidal et al., 2002; Unlü et al., 2006; Caliguri et al., 2006; Bajai et al., 2012), being more frequent in PD than other dystonic tremor diseases.

Objective and easy to administer measures which may detect early PD as well as disease severity or its progression, are still lacking. Biometric research is looking for possible sensors and methods which would allow an objective and precise evaluation of PD patients and their pharmacologic control, even at home (Chen et al., 2011; Patel et al., 2009).

The biometric smart pen BiSP is a biosensor which detects acceleration, velocity, frequency and amplitude of the fine distal movement, finger print and pressure, and permits analysis of the components of a specific movement, like writing the name or drawing of a figure (Takita et al., 2007).

We hypothesized that movement characteristics or features obtained by the biosensor Biometric smart pen-BiSP may permit a classification of movement pattern in Parkinson's disease patients and Non-Parkinson subjects.

Aims

The aims of this study were to analyze the movement features of PD patients and healthy subjects obtained by the biosensor BiSP and to analyze the accuracy of the classification using Support Vector Machine- SVM as the mathematic model.

METHODS

The study was designed as a transversal cohortstudy and was approved by the Ethics Committee on Human Research of Botucatu Medical School, UNESP, Brazil, all participants signed a written consent.

The subjects enrolled were divided into two groups. Group I was composed by 36 PD patients, 25 males, aged 38 to 78 years old, in stable clinical follow-up. We included patients with moderate disease, Hoehn and Yahr classification II or III. Patients with on-off symptoms were excluded.

48 healthy subjects, 15 male, aged 19 to 79 years old were invited to participate (as control group).

Subjects with visual disorders compromising the lecture of the figures, dementia, other tremulous diagnosis than PD, history of alcohol or drug abuse and/or chronic exposure to pesticides were excluded.

After anamnesis and clinical neurologic evaluation, all subjects were orientated to draw four spirals and four meander on a paper model, using the BiSP pen with the dominant hand. The BiSP pen is similar to a normal ink writing pen and allows full visual feedback.

Alternant movement coordination was tested by realizing the diadochokinesia test (pronation-supination test) during 20 seconds of duration, while using the BiSP pen in vertical position in the dominant and in the non-dominant hand.

Data were extracted by the sensors of the BiSP pen (figure 1), containing six sensors for microphone of the roller point, digital pressure of the roller point, pressure of dislocation, inclination and acceleration left to right, inclination and acceleration up to down, inclination and antero-posterior acceleration.

Data evaluation was based on a specifically adapted "Machine Learning (ML)" procedure,using a feature based classification approach.The process of data sampling, data processing, training, matching and classifying was built upon the following sequence of steps:

1. "Clipping" of each measured time series using the BiSP_Expert Tool program, in order to segment the sensor time series to the relevant wanted signal.
2. Storage of all clipped and digitized (1000 Hz) time series into separate data bases using BiSP Sig ID program
3. Feature extraction from all clipped sequences using the BiSP Sig ID program.
4. Application of Support Vector Machine (SVM) with appropriate kernel in order to select a set of eight to twelve adequate classification features ("feature reduction").
5. For training and testing, the total set of all measurements of each object was split into two subsets, the training set composed by 70%, and the test or "query" set, composed by 30% of the measurements.

The tests were classified in true positive, true negative, false positive and false negative; accuracy of the correct classification of each figure was calculated.

To analyze whether age would be a confounding factor, at a second step, subjects of the control group were divided in Young Control Group, composed by individuals aged up to 49 years old, and Old Control Group, by subjects older than 50 years. Classification procedures were repeated for each control group.

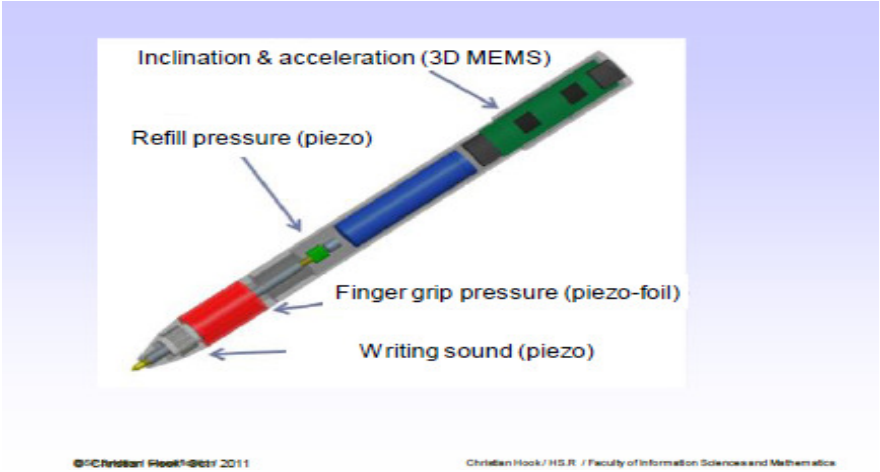

Figure 1. Representation of the biosensor BiSP and its sensors

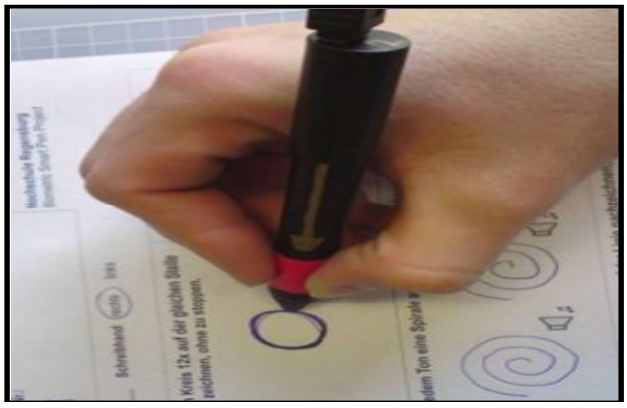

Figure 2. Graphic presentation of the drawing of the figures.

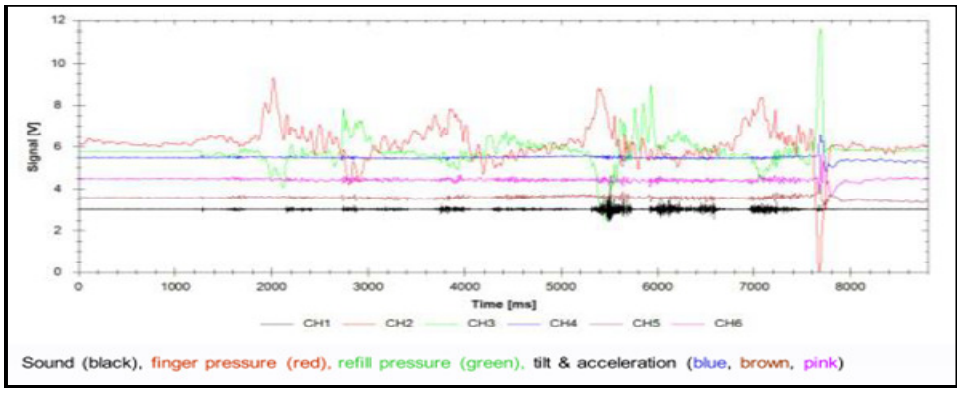

Figure 3. Graphic presentation of the captured signals

RESULTS

36 PD patients, 25 males, aged 38 to 78 years old, in stable clinical follow-up and 48 healthy subjects, 25 male, aged 19 to 79 years old were invited to participate (control group). Both groups were similar for age and gender (Table 1).PD patients showed tremor in 45%, bradycinesisa in 23% and stiffness in 20%.

All participants filled in the drawings in a single session (figure 2). The writing of the figures were executed on a

Table 1. Demographic data of Parkinson's disease group and Control group, and its division into Young Control and Old Control.

	Parkinson's disease Group	Control Group	Young Control	Old Control
Mean age (years)	64	59	35	66
Male subjects	25	25	15	10

- Comparison of results showed no difference ($p>0.05$) between the groups.

Table 2. Accuracy of correct classification of spirales, meander, diadochokinesia of the dominant hand, diadochokinesia of the non-dominant hand and fusion (spiral, meander, diadochokinesia of the dominant hand), testing Parkinson's disease patients versus Control Group, Young Control and Old Control.

	Spiral	Meander	Diadochokinesia dominant hand	Diadochokinesia Non-dominant hand	Fusion
Control Group	**96.7%**	**95.4%**	**92.5%**	**93.6%**	**99.6%**
Young Control	**93.7%**	**89.0%**	**87.2%**	**85.8%**	**99.7**
Old Control	**90.6%**	**88.0%**	**87.2%**	**91.8%**	**99.4**

- Comparison of results showed no difference ($p>0.05$) between the groups.

paper draft using the BiSP pen which is similar to a normal ink writing pen and allows full visual feedback.

For each figure, 8 to 12 features were extracted and submitted to SVM classification. Correct classification of DP and controls showed an accuracy of 96.7% for spirals, 95.4% for meander, for diadochokinesia of the dominant hand of 92.5% and diadochokinesia of the non-dominant hand of 93.6%. Fusion of three figures (spirales, meander and diadochokinesia of the dominant hand) resulted in 99.6% of correct classification (Table 2).

DISCUSSION

Mathematic models are being applied in medicines more and more often, as for the development of models of cardiovascular dynamics, respiratory functions, tumor growth, beside others. The model of Support Vector Machine (SVM) as a classificatory tool has been widely used (Noble, 2006).

The proposal of this study was to analyze the applicability of a biometric sensor BiSP for SVM classification of handwriting features of Parkinson´s disease patients and healthy subjects.

Objective and easy to perform measurements would be helpful for diagnosis of severity and fluctuation of the disease, as patient's self-report information of On-OFF time has subjective perceptual bias, and may not report many features of motor fluctuations used for UPDRS scores. Also, application of the UPDRS scale showed a high reliability when realized by trained physicians, but showed to be examiner-dependent (Post et al., 2005).

Our results showed a high accuracy of correct classification of Parkinson's disease patients and control subjects for different movement tasks. Studies by several other authors showed similar promising results as by Rosenblum et al. (2013), whose pilot study showed correct classification of PD patients and controls, based on measurements of velocity and pressure of writing. Saunders-Pullman et al. (2008) assessed spiral drawing on a digitizing tablet and suggested it might be used as a diagnostic tool even for early Parkinson's disease. Patel et al (2009) studied the objective assessment for the evaluation of the motor task sequence of the *Unified Parkinson Disease Rating Scale*, by using wearable sensors. The integration of wearable sensors and classificatory algorithms showed good applicability to assess the severity of motor symptoms.

Handwriting examinations are often studied as an objective measurement for PD characterization. Micrographia seems to be characteristic for Parkinson's disease even when compared to other SWEDDs patients (subjects without evidence of dopaminergic deficit) (Unlu et al., 2006; Caliguri et al., 2006; Bajai et al., 2012).

Broderick et al. (2009) related that Parkinson's patients had smaller-than required movement amplitude, produced less acceleration and drew smaller-than required sizes. In our study, the objective analysis of the components of the writing movement showed similar results. The most sensitive features were extracted of sensor 3 (pressure on the paper), sensor 4 (vertical excursion) and sensor 5 (velocity). These sensors correspond clinically to the typical symptoms of PD, as tremor (sensor 4), bradykinesia (sensor 5) and stiffness (sensor 3).

Recently, Rosenblum et al (2013) suggested that handwriting might be used as a diagnostic tool. Their pilot study showed correct classification of PD patients and controls, based on measurements of velocity and pressure of writing. We found similar results, with a high

accuracy of correct classification. The repetition of such good results for classification shows that there are typical features in Parkinson's disease patient's handwriting which can be analyzed objectively and, thus, may be used for diagnosis. In our study, we analyzed drawing of figures, as Brazilian population has still a high number of functional analphabets what would induce bias for the writing of the name or other sentences.Spiral drawing has been widely used for analysis of kinematic behaviour. Several authors showed a good correlation of spiral drawing and UPDRS scores (Pullman, 1998) or tremor and speed analysis (Pullman et al., 1995). These authors assessed spiral drawing on a digitizing tablet, and suggested that it could be used as a diagnostic tool even for early Parkinson's disease (Saunders-Pullman et al., 2008; Pullman, 1998).

In our study, we tested different figures, as spirals and meander, beside diadochokinesia as "free movement" in the air. The best accuracy was observed for spirals, free movement analysis as the diadochokinesia were less effective for correct classification. Probably the variation of the position of the sensor in air while executing the altering movement induced too much variables.

Parkinson's disease is most prevalent in older people. But ageing also induces a progressive loss in fine motor coordination. To exclude the bias of age-induced characteristics of the writing patterns, we separated our control group in old and young controls. Similar preoccupation had been presented by Conteras-Vidal et al (2002). In our study, both classifications showed high accuracy suggesting that the selected features are not related to age.

CONCLUSIONS

The biosensor BiSP allows feature extraction of characteristics of movement of the upper limb. SMV analysis of the features showed high accuracy for classification in Parkinson disease and non-Parkinson disease. Computerized analysis of handwriting patterns can identify Parkinson's disease patients and maybe useful as a diagnosis tool.

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