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Dynamics of postural control in Parkinson patients with and without symptoms of freezing of gait

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ABSTRACT

Background: It has been suggested that dynamical measures such as sample entropy may be more appropriate than conventional measures when analyzing time series data such as postural sway. We evaluated conventional and dynamical measures of postural sway in Parkinson disease (PD) patients with and without freezing episodes.
Methods: COP (center of pressure) data were recorded during quiet standing with eyes open, eyes closed and while performing a dual task. Data for 16 patients with freezing of gait, 17 patients with no history of freezing and 24 healthy subjects were analyzed. The amount of postural sway was quantified using conventional measures, whereas for the characterization of the temporal structure of the COP data the normalized sway path and sample entropy was calculated.
Results: Mean radius was higher and sample entropy was lower in patients with freezing symptoms as compared to healthy subjects in all three conditions. Dual-tasking significantly increased sway path length in patients with freezing, while normalized sway path did not change over conditions in this group.
Conclusions: Our findings show that postural sway is characterized by a combination of large radius, short normalized sway path and high regularity of the COP only in patients with freezing. This pattern becomes most prominent in a dual-task paradigm. This may explain higher occurrence of gait freezing in dual task situations with subsequent higher risk of falls. Results suggested that dynamic measures may add valuable information for characterizing postural stability in PD patients.

1. Introduction

Freezing of gait (FOG) is a common clinical symptom in advanced stages of Parkinson disease (PD) [1]. FOG is defined as an episodic inability to start walking and to continue the forward progression as well as episodes of walking with very short shuffling steps [2].

As disease progresses the probability for FOG as well as for postural instability increases leading to serious problems in activities of daily living [1,3]. Postural stability is commonly evaluated by measuring postural sway on a force plate [4]. Studies evaluating postural stability in PD patients found larger sway areas and ranges as well as longer sway paths compared to healthy controls even in the early stage of PD [5–8]. Moreover, an increase of COP area in PD patients while performing an additional dual task was found [9]. A recent study compared aspects of postural control in freezers and non-freezers [10]. The authors found freezers to have a poorer directional control during voluntary weight shifting than non-freezers. These studies used only static measures which are often derived by averaging out the assumed noisy or random character of postural sway (e.g. length of sway path, sway area, radius) to characterize postural sway in PD patients. However, maintaining equilibrium during standing is not a state but a

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dynamical process resulting in a complex time series of center-of-pressure displacements. Variability in such time series is not random noise, but expresses inherent system properties which should be analyzed with additional tools from nonlinear dynamical systems theory (e.g. approximate entropy, Lyapunov exponent) [11]. Indeed, in the last years the use of dynamical parameters to characterize postural sway has become more widespread in postural research [12–16]. This research suggests that dynamical postural parameters are more sensitive to changes in postural control than static measures in elderly subjects or patient groups [13,17].

Only few studies investigated postural control in PD using dynamical parameters [18–20]. Differences in postural stability (an increase in effective stochastic activity in medio-lateral direction) in Parkinson patients were found compared to healthy controls using stabilogram-diffusion analysis (SDA) [18]. Using SDA also abnormal (1 Hz) body sway oscillations (associated with large and fast sway in off treatment state) in PD patients were reported [19]. Less complex patterns in postural sway were observed in patients with PD compared to healthy persons using recurrence quantification analysis (RQA) [20].

To our knowledge there is only one study evaluating static postural control in freezers vs. non-freezers [10]. Also, postural parameters have not yet been investigated in respect to FOG in patients with PD using non-linear mathematical tools. Therefore, the objective of this study was to evaluate the benefit of the additional use of dynamical measures in Parkinson patients to describe postural abilities. As postural abilities vary widely in this population and are associated to the particular symptom of freezing, the patient group was dichotomized into freezers and non-freezers.

2. Methods

2.1. Subjects and measures

All 32 patients were recruited consecutively from the Movement Disorders Outpatient Clinic of the University Hospital of Munich. Inclusion criteria were a diagnosis of PD according to the clinical diagnostic criteria of the UK Parkinson's Disease Society Brain Bank [21] and a stable oral antiParkinson medication. Exclusion criteria were a neurosurgical intervention related to PD (e.g. deep brain stimulation), a neurological, orthopedic or other condition unrelated to PD, which could influence postural stability, and a cognitive state preventing the patient from following the instructions. Twenty-four healthy controls were recruited from a healthy control database from the Department of Orthopedics, Physical Medicine and Rehabilitation.

Patients were dichotomized into "freezers" (15 patients) and "non-freezers" (17 patients). Presence of FOG was evaluated by item 3 of the Freezing of Gait-Questionnaire (FOG-Q) [22]. Patients who never experienced FOG were classified as non-freezers. Subjects who experienced FOG rarely or often FOG were classified as freezer and were further screened with all items of the FOG-Q. Scores range from 0 to 29, with higher scores indicating greater severity of FOG.

The Hoehn and Yahr (H&Y) staging scale was used for describing severity of PD. The H&Y scale rates the severity of Parkinson's symptoms progress in five stages, with 1 being the mildest (unilateral symptoms only) and 5 the worst (confinement to bed or wheelchair unless aided).

For identification of postural instability the Rapid Assessment of Postural Instability in Parkinson's Disease (RAPID) [23] was used. This questionnaire consists of 3 parts: 1 item evaluating difficulties in performing activities of daily living; 2 item fear of falling and 3 item frequency of falls during the last 3 months.

Before entering the study an informed written consent according to the Declaration of Helsinki was obtained from all the subjects in the study.

2.2. Experimental set-up and procedure

For collecting postural data the force distribution measurement system FDM-T (zebris medical GmbH, Germany) was used. The system consists of a treadmill (H/P Cosmos) with an integrated, calibrated measuring force sensor matrix. Displacements of the center of pressure (COP) were measured with a sampling frequency of 100 Hz for 30 s during quiet upright standing under three conditions: upright standing with eyes open (EO) and eyes closed (EC) and upright standing with eyes closed while performing a cognitive dual task (EC-DT). During the trial with EO, subjects were instructed to look straight ahead on a white wall. The EC-DT condition consisted of counting loud backwards beginning at 100. Participants were instructed to stand with arms hanging loose next to their body with feet at shoulder-width and to avoid any voluntary movements during data recording. All patients were evaluated in the best "on" state to minimize involuntary movements such as tremor or dyskinesia [7].

2.3. Data processing

Raw data of the medio-lateral as well as the anterior–posterior direction first were bidirectionally filtered (second-order low-pass Butterworth filter; cut-off frequency of 10.0 Hz) to eliminate measurement noise. After omitting the first 0.85 s (due to use of the Butterworth filter) the remaining x and y time series (2915 data points) were used to calculate COP dynamics (in this study sample entropy) and several summary statistics, which by definition ignore the temporal structure of a time series.

The total length of the COP trajectory (sway path; SP) was calculated by adding up the distances between consecutive data points calculated as $\sqrt{((x_n - x_{n+1})^2 + (y_n - y_{n+1})^2)}$ (see [12,17]). After subtracting the mean of each x and y time series the mean radius (r) was calculated according to $\sum r_i = \sqrt{x_I^2 + y_i^2}$ (see [24]). Also, the normalized sway path (SPn) was calculated to get a scale independent measure by subtracting the mean for each x and y time series and dividing them by their respective standard deviation to unit variance. Given the same standard deviation after normalization and the same number of data points for all time series, a longer SPn is related to the structure of the time series (i.e. more curvings or "twists and turns" [8]) in contrast to SP whose amount is also related to the statistical spread of the time series. Although SPn gives an information about the structure it ignores the temporal course of a time series.

To further evaluate the temporal structure of the COP trajectories sample entropy was used [14,25]. Sample entropy (SE) is a method to index complexity/regularity of time series [25]. Smaller SE values indicate a more regular signal as low values arise from a high probability of repeated sequences in the signal. In contrast, highly irregular COP time series are characterized by matching epochs that tend to be followed by data samples of different values, resulting in larger SE estimates. SE is quantified as the negative natural logarithm of the conditional probability that a sequence of data points (m), will also repeat itself for $m + 1$ data points within a tolerance r (formalized as: $SE(m, r, N) = (-1) \cdot \log(A(r)/B(r))$) [12,26]. A denotes the total number of template matches in the $(m + 1)$-dimensional and B in the m-dimensional phase space within the tolerance r. The matching tolerance r defines whether points are similar or not which corresponds to the decision of whether the sequence has repeated itself or not. The matching tolerance is not a fixed value but is normalized (divided by the respective standard deviation) for every time series in order to ease the comparison