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Postural control and freezing of gait in Parkinson's disease

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A B S T R A C T

Introduction: The relationship between freezing of gait (FOG) and postural instability in Parkinson's disease (PD) is unclear. We analyzed the impact of FOG on postural control.
Methods: 31 PD patients with FOG (PD+FOG), 27 PD patients without FOG (PD-FOG) and 22 healthy control (HC) were assessed in the ON state. Postural control was measured with the Fullerton Advanced Balance (FAB) scale and with center of pressure (COP) analysis during quiet stance and maximal voluntary forward/backward leaning.
Results: The groups were balanced concerning age, disease duration and disease severity. PD+FOG performed significantly worse in the FAB scale (21.8 ± 5.8) compared to PD-FOG (25.6 ± 5.0) and HC (34.9 ± 2.4) (mean ± SD, $p < 0.01$). PD+FOG had impaired ability to voluntary lean forward, difficulties to stand on foam with eyes closed and reduced limits of stability compared to PD-FOG ($p < 0.05$). During quiet stance the average anterior–posterior COP position was significantly displaced towards posterior in PD+FOG in comparison to PD-FOG and HC ($p < 0.05$). The COP position correlated with severity of FOG ($p < 0.01$). PD+FOG and PD-FOG did not differ in average COP sway excursion, sway velocity, sway regularity and postural control asymmetry.
Conclusions: PD+FOG have reduced postural control compared to PD-FOG and HC. Our results show a relationship between the anterior–posterior COP position during quiet stance and FOG. The COP shift towards posterior in PD+FOG leads to a restricted precondition to generate forward progression during gait initiation. This may contribute to the occurrence of FOG or might be a compensatory strategy to avoid forward falls.

1. Introduction

Freezing of gait (FOG) in Parkinson's disease (PD) is defined as a “brief, episodic absence or marked reduction of forward progression of the feet despite having the intention to walk” [1]. The pathophysiology of FOG is not yet fully understood and several hypotheses about the potential mechanisms behind the symptom exist (for review see Ref. [2]). Postural control is required during gait initiation when the center of mass is shifted on one leg while the other leg initiates the first step. During walking or turning dynamic postural control is involved, especially when turns are performed with a small radius and gait becomes less regular [3]. The relationship between postural control and FOG is not yet assessed in detail.

When analyzing static postural control previous studies have shown that during quiet stance patients with FOG (PD+FOG) do not differ in the average center of pressure (COP) excursion, COP velocity and sway regularity in comparison to patients without FOG (PD-FOG) [4,5]. However, the study conducted by Nantel et al. [5] found a significant correlation between the severity of FOG and average anterior–posterior (AP) COP excursion and medio-lateral COP velocity. The results of both studies have to be interpreted

List of abbreviations: AP, anterior–posterior; CI, confidence interval; EC, eyes closed; FAB, Fullerton Advanced Balance; FOG, freezing of gait; FOGQ, Freezing of Gait Questionnaire; HC, healthy control; H&Y, Hoehn and Yahr; LOS, limits of stability; ML, medio-lateral; PD, Parkinson's disease; PD+FOG, patients with FOG; PD-FOG, patients without FOG; RMS, root mean square; SEn, sample entropy; SI, symmetry index; UPDRS, Unified Parkinson's Disease Rating Scale.

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with caution, as PD+FOG and PD-FOG significantly differed concerning disease duration and disease severity [4,5]. It has been shown that PD+FOG have reduced directional control during voluntary weight shifting [6].

With respect to reactive postural control evidence exist that PD+FOG perform significantly worse in the pull test in comparison to PD-FOG [7]. Smulders et al. [8] analyzed compensatory stepping responses during backward perturbations and showed that PD+FOG have smaller step lengths in comparison to PD-FOG whereas PD+FOG do not differ concerning onset and number of steps. PD+FOG have no deficits in shifting between different postural control sets [8] and postural strategies during sensory manipulations do not differ compared to PD-FOG [6]. As gait asymmetry is related to FOG [9], one study analyzed asymmetry in postural control during stance perturbations but no relationship to FOG was found [10]. It has been shown that the overall balance performance is reduced in PD+FOG compared to PD-FOG [11].

When analyzing gait initiation it has been shown that anticipatory postural adjustments are not different between PD+FOG and healthy control (HC) [12]. Proprioceptive deficits may be one reason why PD+FOG differ in some aspects of postural control in comparison to PD-FOG [13]. It is suggested that FOG and postural instability underlie different pathophysiological mechanisms [14].

Taken together the current literature indicates that PD+FOG differ in some but not all aspects of postural control. Insufficient sample sizes and the lack of age-, disease duration- and disease severity matched groups of some of these studies make it difficult to clearly characterize postural control deficits of PD+FOG.

Postural control is multidimensional and involves static/dynamic and feedforward/feedback processes. The aim of the present descriptive study was to clarify in an explorative approach if and which postural control deficits exist in PD+FOG in comparison to PD-FOG and HC. First, we used a multidimensional clinical balance scale to analyze whether PD+FOG are postural instable in comparison to PD-FOG and HC. We consider clinical balance scales as useful tools to assess overall balance performance as they are able to reflect various dimensions of postural control. Furthermore, by analyzing subitems of the scale we wanted to describe postural control deficits in more detail. To our best knowledge this is the first study using the subitems of a multidimensional clinical balance scale to characterize postural control in PD+FOG in detail. Second, COP measurements were conducted during quiet stance and during maximal voluntary forward and backward leaning. Specifically, beside other COP based outcomes we wanted to analyze the average anterior–posterior COP position during quiet stance and no other study focused on that aspect before. We anticipated that start hesitation may be related to an altered stance position in PD+FOG. Furthermore we aimed to assess postural asymmetry during quiet stance and during maximal forward and backward leaning to see if there is any relationship to FOG.

2. Methods

2.1. Participants

31 PD+FOG, 27 PD-FOG and 22 HC participated in this study. Patients were recruited from the Neurology Department University Hospital Schleswig–Holstein and from the PD support group, Kiel, Germany. The patients' spouses served as healthy control. Evaluations were performed between February 2012 and December 2014. PD patients were diagnosed according Brain Bank Criteria for PD and were classified to be PD+FOG if they scored $\geq$1 point on question three of the Freezing of Gait Questionnaire (FOGQ) [15]. FOG and its subtypes were carefully explained and demonstrated by the examiner before completing the FOGQ. Participants were encouraged to have another person present to add detail or to confirm the patient's statement. The following exclusion criteria were applied: any other neurological disorders other than PD, deep brain stimulation (PD patients only). PD groups were well balanced for disease duration and motor symptom severity, and all groups were fairly balanced for age. Disease severity was assessed with the Unified Parkinson's Disease Rating Scale (UPDRS) part 3 and the Hoehn & Yahr (H&Y) scale. The study protocol was approved by the local ethics committee and all participants gave written informed consent prior to participating.

2.2. Testing procedure

Patients were assessed in the ON state of medication. Postural control was assessed as follows:

(1) The Fullerton Advanced Balance (FAB) scale was performed to assess postural control with a clinical balance scale [16]. The FAB scale is a 10-item test instrument with a 5-point ordinal scale for each item (0–4 points) and a maximal score of 40 points (higher values indicate better performance). The FAB scale is validated for individuals with PD demonstrating excellent interrater and test-retest reliability [17].

(2) Center of pressure (COP) displacements of postural sway was measured using a Zebris FDM-S force measuring plate (Zebris Medical GmbH, Isny, Germany) with a 100 Hz sampling frequency. The COP is the location of the vertical ground reaction vector on the surface on which the subject stands. Subjects stood barefoot on the plate with their hands on the hip and were instructed to look straight ahead on a white wall. All participants placed their feet with standardized heel-to-heel distance (11 cm) on the same position of the plate using a positioning device which was eliminated before starting the measurement [18]. The analysis consisted of two parts: The first 30 s participants were instructed to stand normal. Thereafter, subjects were required to lean as far forward and as far backward as possible without moving the feet or bending at the hips. Subjects had to hold their limits of stability (forward and backward) for 5 s, respectively. The participants had two attempts at the test, and the trial with the greater limit of stability (LOS) was considered for further analysis.

In order to let the subjects perform each test under the same physical conditions, a seated rest was proposed by the assessor several times. If the assessor gained the impression that a participant suffered from fatigue, a seated rest was given.

2.3. Data analysis

COP data were filtered using a second-order low-pass Butterworth filter (cutoff frequency 10 Hz). Due to the use of the filter, 2915 data points of the first 30 s recording remained to calculate the following variables: (1) average anterior–posterior (AP) COP position expressed as percentage of foot lengths; (2) root mean square (RMS) distance relative to the mean COP position to quantify the magnitude of COP displacements; (3) mean COP velocity and (4) sample entropy (SEn).

We are using SEn to exam the degree of irregularity of postural sway. When the signal is not changing strongly, SEn is lower; if it is irregular, SEn is higher. We proceed SEn refer to the algorithms of Richman [19] as follows: