



## Postural control, falls and Parkinson's disease: Are fallers more asymmetric than non-fallers?

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### ABSTRACT

Postural control asymmetry is an important aspect of Parkinson's disease (PD) that may be associated with falls. The aim of this study was to compare the postural control asymmetry during postural tasks between fallers and non-fallers in people with PD and neurological healthy age-matched controls (CG). Individuals with idiopathic PD ( $n = 24$ ) and CG ( $n = 24$ ) were sub-divided into groups of fallers and non-fallers based on their fall history over the past year. Participants performed blocks of three 30-s trials of quiet standing with feet in a side-by-side and semi-tandem stance position. The center of pressure parameters for each limb were measured and used to calculate the symmetry index. Fallers compared to non-fallers had decreased asymmetry of vertical force in the side-by-side condition. During the tandem-front leg condition, PD non-fallers increased asymmetry of the medial-lateral velocity of sway compared to CG non-fallers. In addition, for the tandem-back leg condition, PD non-fallers increased asymmetry of total displacement and medial-lateral root mean square and mean velocity of sway compared to PD fallers. The results of the study did not support the hypothesis that PD fallers are more asymmetric than PD non-fallers. On the contrary, our results indicated that PD non-fallers had higher postural control asymmetry, especially during the more challenging (semi-tandem standing) postural task.

### 1. Introduction

Impairment of postural control increases the risk of falls in people with Parkinson's disease (PD) (Bloem, Hausdorff, Visser, & Giladi, 2004; Carpenter, Allum, Honegger, Adkin, & Bloem, 2004; Rocchi, Chiari, & Horak, 2002). People with PD experience two to three times more falls than healthy older adults (Bloem et al., 2004; Pickering et al., 2007). Postural deficits with PD include impairment of postural reflexes, reduced limits of stability, postural instability, freezing and festination, and difficulty in executing and timing responses to external challenges and unexpected perturbations (Beretta et al., 2015; Boonstra, van Kordelaar, Engelhart, van Vugt, & van der Kooij, 2016; Simieli et al., 2017; Vítório et al., 2013). Another aspect of PD that may be associated with falls is

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postural control asymmetry. Our group demonstrated that falls in PD can be predicted by asymmetry in the anterior-posterior mean velocity of center of mass during a unipedal standing task (Beretta et al., 2018), which is considered a postural challenging task. However, little is known about the influence of postural control asymmetry on falls in this population and whether PD fallers have more asymmetric postural control than non-fallers, especially during more challenging postural tasks.

Asymmetric motor symptoms are a common characteristic in PD (Djaldetti, Ziv, & Melamed, 2006; Lewis et al., 2009) and are thought to be due to asymmetric dopaminergic loss in the substantia nigra (Lewis et al., 2009). Compared to healthy controls, people with PD exhibit greater postural asymmetry (Barbieri et al., 2016; Beretta et al., 2015; Boonstra et al., 2016; Boonstra, Van Vugt, Van Der Kooij, & Bloem, 2014; Carpenter et al., 2004; Geurts et al., 2011; Rocchi et al., 2002; Van Der Kooij, Van Asseldonk, & Nederhand, 2007), especially during more challenging postural tasks (Barbieri et al., 2016; Beretta et al., 2015). Many situations in daily life rely on symmetrical postural control, such as responding to a balance perturbation or walking, to avoid falls. In these situations, individuals with PD compensate for motor asymmetries by increasing the relative contribution of the least impaired leg to postural control (Boonstra et al., 2014). While, this asymmetric control of posture in people with PD may be effective in simple standing tasks, it may lead to increased instability and falls under more challenging postural situations (Beretta et al., 2018). Therefore, the question of this study is: Do PD fallers have more postural control asymmetries compared to PD non-fallers and healthy controls?

The aim of this study was to compare the postural control asymmetry during postural tasks (side-by-side and semi-tandem standing) between fallers and non-fallers in people with PD and healthy age-matched controls. We hypothesized that people with PD would have more postural control asymmetries than the control group. Based on prior associations found between postural asymmetry and falls (Beretta et al., 2018), we also expected that PD fallers would have greater postural asymmetry than PD non-fallers.

## 2. Methods

### 2.1. Participants

Forty-eight individuals participated in this study. Twenty-four people with idiopathic PD (ten men) were selected from a specialized PD center in São Paulo – Brazil. For the CG, 24 neurologically healthy individuals were selected (Table 1). The groups were matched according to their sex, age, body mass and height. The study was approved by the research ethics committee of the São Paulo State University at Rio Claro – Brazil (#0227/2013) and each participant provided written informed consent to participate in the study. A power-analysis (G\*Power software) based on previously published data (Barbieri et al., 2016; Beretta et al., 2015) indicated that a sample size of at least 39 individuals (10 in each group) was needed for a 95% probability to detect a difference of 20% between the groups for the primary outcome with a type I error of 0.05.

Individuals with PD had their diagnoses confirmed by expert neurologists according to the UK Brain Bank Criteria (Hughes, Daniel, Kilford, & Lees, 1992). The following exclusion criteria were used: under 60 years of age; a Hoehn & Yahr Scale – H&Y (Goetz et al., 2004) score above three for the PD group; cognitive decline (Mini Mental State Examination (MMSE) score < 23); and musculoskeletal, orthopedic and/or visual impairments that would prevent the subject from performing the required tasks. In addition, only people with PD on anti-Parkinson medication were included. CG had no known neurological illnesses.

### 2.2. Falling and non-falling individuals

Subjects were drawn from a larger sample of individuals that had their falls recorded over a 2 year period by weekly phone calls and/or personal interview. First, PD fallers, that had personal interviews, were drawn blindly and, in the sequence of the PD non-fallers, CG fallers and non-fallers were matched for PD fallers. Each group (people with PD and CG) was composed of 12 fallers (at

**Table 1**

Means and standard deviations of demographic and clinical characteristics of PD and CG-fallers and non-fallers and range of UPDRS items punctuation for PD-faller and non-faller. MMSE - Mini Mental State Examination; H&Y–Hoehn &Yahr scale; UPDRS–Unified Parkinson’s Disease Rating Scale.

	People with PD		Control group	
	Faller (n = 12; 4 women)	Non-Faller (n = 12; 5 women)	Faller (n = 12; 6 women)	Non-Faller (n = 12; 6 women)
Age (years)	69.92 ± 4.03	70.83 ± 7.30	68.75 ± 5.89	70.67 ± 7.01
Body mass (kg)	69.88 ± 8.91	74.52 ± 12.58	69.12 ± 13.92	69.73 ± 10.35
Height (m)	1.61 ± 0.08	1.60 ± 0.08	1.62 ± 0.08	1.61 ± 0.09
MMSE (score)	28.00 ± 2.30	27.75 ± 2.14	29.17 ± 1.53	29.00 ± 1.35
Disease duration (years)	4.38 ± 2.32	5.58 ± 2.87	–	–
H&Y (stage)	1.71 ± 0.49	1.75 ± 0.46	–	–
UPDRS motor (score)	25.5 ± 12.07	26.00 ± 7.32	–	–
Side of PD (score)	–3–1	–3–2	–	–
Levodopa equivalent dose (mg/day)	599.17 ± 409.19	488.54 ± 269.33	–	–
Total number of falls	21	–	14	–

least one fall in the last year) and 12 non-fallers (without recent history of falling over the last year) individuals. A fall was defined as unintentionally coming to the ground or some lower level not as a result of a major intrinsic event or overwhelming hazard (Wood, Bilclough, Bowron, & Walker, 2002). Falls in CG were idiopathic, as CG fallers did not have any known balance or gait impairments or any disease that explained their falls. The number of falls for each participant was recorded over the prior 4-month period.

### 2.3. Clinical evaluation and side of PD

The individuals with PD performed the tasks in the ON medication state, approximately one hour after taking their normal dose of dopaminergic medication. All participants were evaluated by an expert neuropsychiatrist, and completed the Mini-Mental State Examination (Brucki, Nitrini, Caramelli, Bertolucci, & Okamoto, 2003) to verify their cognitive status. Next, they were evaluated clinically to determine the stage of PD, using the H&Y scale and the motor portion of the UPDRS (Fahn & Elton, 1987).

Footedness was assessed for each participant by asking them to stand on one leg (Sadeghi, Allard, Prince, & Labelle, 2000); the stance limb that was initially selected by the participant was considered their preferred limb. Two PD fallers and two CG fallers were left limb dominant. We determined the least and most affected limbs for people with PD based on the difference between the UPDRS scores for the right and left limbs for items #20–23 and 25–26 (Stewart et al., 2009) (Table 1).

### 2.4. Postural control tasks

Two separate force plates (200 samples/s) – 50 × 50 cm (AccuGait, Advanced Mechanical Technologies, Boston, MA) were used to analyze postural control. The force plates were positioned at a distance of 5 cm from each other. Participants positioned one foot on each force plate in either side-by-side and semi-tandem positions. In both tasks, participants were instructed to stand quietly in an upright position for 30 s, and keep their gaze directed at a target that was positioned at eye level 1 m away from them. For the side-by-side standing, participants performed 3 trials with their feet positioned in parallel to each other, hip-width apart. For semi-tandem standing, participants positioned one foot in front of the other with a heel-to-toe distance of 10 cm. Participants performed three trials with least affected/preferred leg positioned in front (front-leg) or back (back leg). For each of the tasks, the location of the participant's feet was recorded on a sheet to allow each participant to maintain the same foot position for each trial. The block of side-by-side standing trials were performed first, followed by the blocks of semi-tandem standing trials (front leg/back leg) in a randomized order.

### 2.5. Data analysis

The first 10 s of each recording was not analyzed in order to account for non-stationarities known to occur during this period (Duarte, Harvey, & Zatsiorsky, 2000). The mean center of pressure (CoP) signal was calculated for each trial. The data was then filtered with a fourth order low-pass Butterworth filter with a cut-off frequency (5 Hz) determined by residual analysis. For each standing condition, the resultant CoP signal of the ground reaction forces was determined in a 2-dimensional transverse plane by means of digital moment-of-force calculations for each force plate (Geurts et al., 2011; Rocchi et al., 2002).

The following CoP parameters were analyzed for each leg separately, with the experimenter blinded to the group assignment: total displacement (i.e., the length of the CoP trajectory on the support base); mean velocity (i.e., the displacement of the total sway of the CoP divided by the total duration of the trial – anterior-posterior and medial-lateral directions); and root mean square (RMS) (i.e., the CoP variability around the mean CoP trajectory) in the – anterior-posterior and medial-lateral directions. In addition, we analyzed the mean of vertical force (i.e. weight distribution) of both limbs during the tasks.

CoP parameters for each limb and participant were averaged across the three trials and used to calculate the following symmetry index (percentage) (Barbieri et al., 2016; Beretta et al., 2015; Herzog, Nigg, Read, & Olsson, 1989):

People with PD

$$\frac{\text{least affected} - \text{most affected}}{\text{least affected} + \text{most affected}} \times 100$$

Control group

$$\frac{\text{preferred limb} - \text{non - preferred limb}}{\text{preferred limb} + \text{non - preferred limb}} \times 100$$

For semi-tandem task, the symmetry index was calculated considering front leg (tandem – front leg) and back leg (tandem – back leg). An example of the equation used for front leg is presented below.

$$\frac{\text{least affected front leg} - \text{most affected front leg}}{\text{least affected front leg} + \text{most affected front leg}} \times 100$$

A value of zero per cent for index indicates that there is no difference between sides. We calculated the absolute value of the symmetry index for each subject's COP parameters (Barbieri et al., 2016; Beretta et al., 2015), with higher percentage values indicating higher asymmetry.

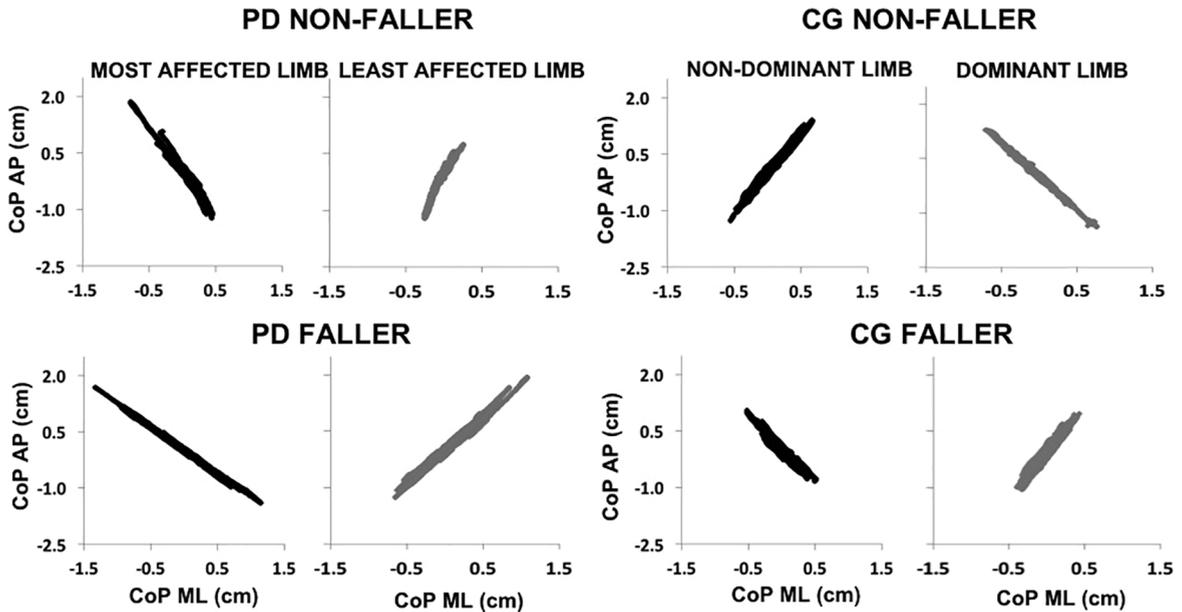


Fig. 1. A typical example of the displacement of sway in a faller and non-faller from the PD and control groups during semi-tandem standing (back-leg). Black lines represent most affected or non-dominant limb and gray lines represent least affected or dominant limb.

## 2.6. Statistical analysis

The data were normally distributed, and the assumption of sphericity was not violated, as verified by the Shapiro–Wilk and Mauchly tests, respectively. Two-way ANOVAs with factors for group (people with PD  $\times$  CG) and falls (fallers  $\times$  non-fallers) were used to analyze effects on MMSE, and symmetry index separately for each stance condition. In addition, the COP parameters were compared through two-way ANOVAs with factors for falls and limb (least affected limb or dominant limb  $\times$  most affected limb or non-dominant limb), separately for each group and stance condition. This analysis was used to determine the effective influence from each limb during postural control. Significant interactions were further analyzed using Tukey's post hoc tests. The clinical characteristics (disease duration, H&Y, UPDRS motor and side of PD score) and levodopa equivalent dose of PD fallers and non-fallers were compared using t-tests. Statistical analyses were performed using SPSS software (version 18.0) for Windows ( $p < 0.05$ ). The effect size was calculated for symmetry index statistical analysis and interpreted as small (effect size  $< 0.2$ ), medium (effect size between 0.3 and 0.7), and large (effect size  $> 0.8$ ) (Cohen, 1988).

## 3. Results

No significant main, or interaction effects were observed for MMSE ( $p = 0.250$ ) and UPDRS ( $p = 0.507$ ) scores. In addition, there were no significant differences in clinical characteristics and levodopa equivalent dose between PD fallers and non-fallers ( $p = 0.442$ ). All individuals with PD had postural asymmetry. Fifty per cent of PD fallers and 50% of PD non-fallers had greater asymmetry toward the least affected limb while also 50% of CG fallers and 75% of CG non-fallers had greater asymmetry toward the dominant limb, respectively. In addition, six PD non-fallers and eight PD fallers were right-footed. Fig. 1 illustrates the displacement of sway for PD and CG fallers and non-fallers according to limb preference and most and least affected limb, respectively.

Significant main effects of group were observed in the side-by-side condition, with increased asymmetry of total displacement (% difference between sides = 5.68%;  $F_{1,44} = 4.07$ ), medial-lateral RMS (% difference between sides = 5.55%;  $F_{1,44} = 3.83$ ) and mean velocity of sway (% difference between sides = 8.76%;  $F_{1,44} = 6.51$ ) observed in people with PD compared to controls (Tables 2 and 3). A significant main effect of falls indicated that fallers compared to non-fallers had decreased asymmetry of vertical force in side-by-side condition (% difference between sides = 3.78%;  $F_{1,44} = 7.38$ ). No significant group\*falls interactions ( $p > 0.05$ ) were observed for side-by-side standing. A significant main effect of falls was observed for people with PD, with greater anterior-posterior RMS ( $F_{1,22} = 6.71$ ,  $p = 0.017$ ) observed in PD fallers compared to PD non-fallers. Likewise, there was a significant main effect of falls for CG with lesser total displacement of sway ( $F_{1,22} = 5.74$ ,  $p = 0.025$ ), anterior-posterior ( $F_{1,22} = 8.31$ ,  $p = 0.009$ ) and medial-lateral ( $F_{1,22} = 4.80$ ,  $p = 0.039$ ) RMS in CG fallers compared to CG non-fallers. A significant main effect of limb was observed for people with PD and CG, which indicated a higher total displacement of sway ( $F_{1,22} = 4.88$ ,  $p = 0.038$ ) in the most affected limb, and faster anterior-posterior velocity of sway ( $F_{1,22} = 5.12$ ,  $p = 0.034$ ) and reduced vertical force ( $F_{1,22} = 4.51$ ,  $p = 0.045$ ) in non-dominant limb, respectively. Moreover, a fall \* limb interaction was indicated for total displacement of sway in people with PD, and anterior-posterior velocity of sway and vertical force in CG. PD non-fallers presented higher total displacement of sway in most affected limb compared to least affected limb ( $F_{1,22} = 5.15$ ,  $p = 0.034$ ), while CG non-fallers presented faster anterior-posterior

**Table 2**  
Means and standard deviations of index asymmetry of body sway parameters for fallers and non-fallers people with PD (PD) and neurologically healthy individuals (CG) in each stance condition. The effect size is presented in parentheses after p-values (only for significant values). AP – anterior-posterior; ML – medial-lateral.

Condition		Displacement (%)	RMS - AP (%)	RMS - ML (%)	Mean velocity - AP (%)	Mean velocity - ML (%)	Vertical force (%)
Side-by-side	PD	Faller	15.25 ± 9.10	14.89 ± 9.39	12.26 ± 6.61	14.47 ± 10.69	5.27 ± 4.87
		Non-faller	18.90 ± 10.37	18.73 ± 11.21	13.39 ± 6.67	22.07 ± 14.17	10.34 ± 5.333
	CG	Faller	12.63 ± 5.15	12.31 ± 4.94	6.29 ± 6.65	12.20 ± 8.13	4.78 ± 2.44
		Non-faller	12.02 ± 6.87	11.63 ± 7.43	13.80 ± 11.53	8.73 ± 8.19	7.28 ± 5.89
	p-values	group	<b>0.047</b> (0.57)	0.566 (0.008)	0.049 (0.55)	<b>0.012</b> (0.69)	0.209 (0.021)
	falls	0.521 (0.009)	0.520 (0.009)	0.526 (0.008)	0.503 (0.010)	<b>0.009</b> (0.732)	
	group*falls	0.370 (0.018)	0.944 (0.001)	0.366 (0.019)	0.182 (0.040)	0.077 (0.069)	
Semi tandem-front-leg	PD	Faller	27.51 ± 13.94	26.27 ± 18.51	23.33 ± 16.42	20.52 ± 17.39	7.94 ± 4.07
		Non-faller	27.46 ± 18.45	25.18 ± 9.54	25.52 ± 11.98	29.67 ± 18.44	7.73 ± 5.29
	CG	Faller	23.70 ± 7.18	24.12 ± 14.55	24.93 ± 10.71	21.03 ± 9.78	10.13 ± 6.32
		Non-faller	13.48 ± 7.44	25.14 ± 13.40	13.39 ± 7.97	13.82 ± 8.32	6.10 ± 3.46
	p-values	group	<b>0.019</b> (0.660)	0.760 (0.002)	0.069 (0.230)	0.068 (0.180)	0.842 (0.002)
	falls	0.167 (0.043)	0.972 (0.001)	0.262 (0.029)	0.815 (0.001)	0.142 (0.017)	
	group*falls	0.172 (0.042)	0.768 (0.002)	0.128 (0.052)	0.450 (0.013)	0.050 (1.185)	
Semi tandem-back-leg	PD	Faller	10.53 ± 3.77	11.35 ± 5.52	16.11 ± 11.93	12.58 ± 10.40	2.87 ± 2.39
		Non-faller	19.38 ± 11.68	16.64 ± 14.25	18.33 ± 17.84	23.57 ± 11.76	2.60 ± 3.11
	CG	Faller	10.63 ± 5.60	14.47 ± 9.49	14.15 ± 7.42	15.67 ± 10.87	2.12 ± 1.53
		Non-faller	10.22 ± 4.72	8.94 ± 4.72	11.80 ± 6.68	10.19 ± 8.44	3.82 ± 1.59
	p-values	group	<b>0.034</b> (0.572)	0.399 (0.016)	0.063 (0.190)	0.126 (0.052)	0.095 (0.062)
	falls	<b>0.047</b> (0.533)	0.966 (0.001)	0.095 (0.062)	0.738 (0.003)	0.366 (0.019)	
	group*falls	<b>0.030</b> (1.124)	0.048 (0.812)	<b>0.050</b> (1.010)	0.329 (0.022)	<b>0.009</b> (1.320)	

**Table 3**

Means and standard deviations of raw data of CoP parameters for fallers and non-fallers people with PD (PD) and neurologically healthy individuals (CG) in each stance condition. AP – anterior-posterior; ML – medial-lateral; LL – least affected limb; ML – most affected limb.

Condition		Limb	Displacement (cm)	RMS – AP	RMS – ML	Mean velocity - AP (cm/s)	Mean velocity - ML (cm/s)	Vertical force (N)	
Side-by-side	PD	Faller	LL	800.15 ± 224.13	0.24 ± 0.06	0.04 ± 0.01	0.59 ± 0.23	0.12 ± 0.02	349.89 ± 57.29
			ML	882.14 ± 264.13	0.26 ± 0.07	0.04 ± 0.02	0.63 ± 0.18	0.13 ± 0.03	343.04 ± 43.74
	Non-faller	LL	733.18 ± 215.79	0.25 ± 0.09	0.03 ± 0.01	0.63 ± 0.37	0.12 ± 0.04	345.89 ± 56.86	
		ML	947.94 ± 299.33	0.29 ± 0.09	0.03 ± 0.01	0.71 ± 0.36	0.12 ± 0.04	362.14 ± 56.37	
	CG	Faller	DL	703.00 ± 131.16	0.22 ± 0.04	0.03 ± 0.01	0.59 ± 0.21	0.25 ± 0.21	337.26 ± 67.19
			NDL	702.68 ± 159.03	0.22 ± 0.04	0.03 ± 0.01	0.58 ± 0.24	0.27 ± 0.24	322.16 ± 69.75
Semi tandem–front-leg	PD	Faller	LL	1233.88 ± 610.81	0.34 ± 0.18	0.16 ± 0.07	1.32 ± 0.71	0.62 ± 0.37	233.65 ± 85.33
			ML	1620.89 ± 737.76	0.43 ± 0.20	0.22 ± 0.12	1.63 ± 0.80	0.80 ± 0.58	221.94 ± 64.93
	Non-faller	LL	1099.79 ± 632.08	0.41 ± 0.35	0.17 ± 0.22	1.69 ± 1.63	0.45 ± 0.31	252.46 ± 69.92	
		ML	1636.66 ± 764.53	0.43 ± 0.15	0.17 ± 0.22	1.68 ± 1.01	0.43 ± 0.18	280.96 ± 78.66	
	CG	Faller	DL	1729.00 ± 736.58	0.50 ± 0.23	0.20 ± 0.11	2.18 ± 1.13	0.93 ± 0.49	252.43 ± 81.75
			NDL	1475.16 ± 837.62	0.42 ± 0.22	0.16 ± 0.13	1.66 ± 0.80	0.64 ± 0.59	218.90 ± 81.09
Semi tandem–back-leg	PD	Faller	LL	2132.03 ± 643.13	0.58 ± 0.19	0.33 ± 0.09	1.96 ± 1.02	1.06 ± 0.48	470.64 ± 71.71
			ML	2141.21 ± 507.81	0.53 ± 0.16	0.39 ± 0.09	1.87 ± 0.89	1.40 ± 0.55	459.00 ± 60.00
	Non-faller	LL	1971.70 ± 577.94	0.52 ± 0.14	0.32 ± 0.15	1.98 ± 1.28	1.22 ± 0.92	441.37 ± 73.93	
		ML	1961.92 ± 812.07	0.52 ± 0.23	0.32 ± 0.15	1.86 ± 1.18	1.13 ± 0.73	436.56 ± 111.63	
	CG	Faller	DL	1750.50 ± 422.68	0.48 ± 0.21	0.24 ± 0.08	1.94 ± 0.72	0.94 ± 0.29	438.45 ± 76.67
			NDL	1694.36 ± 580.36	0.49 ± 0.21	0.23 ± 0.07	1.92 ± 0.76	0.86 ± 0.34	442.22 ± 85.41
Non-faller	DL	2022.62 ± 846.13	0.56 ± 0.21	0.26 ± 0.12	2.24 ± 0.94	1.01 ± 0.45	441.82 ± 71.77		
	NDL	2050.60 ± 678.64	0.58 ± 0.21	0.27 ± 0.11	2.13 ± 0.71	1.07 ± 0.41	421.03 ± 79.54		

velocity of sway ( $F_{1,22} = 4.50$ ,  $p = 0.013$ ) and reduced vertical force ( $F_{1,22} = 4.54$ ,  $p = 0.048$ ) in non-dominant limb compared to dominant limb.

Significant main effects of group were observed during the tandem – front leg condition, with increased asymmetry of total displacement (% difference between sides = 8.99%;  $F_{1,44} = 5.91$ ) observed in people with PD compared to CG (Tables 2 and 3). A group \* falls interaction was observed for asymmetry of medial-lateral velocity of sway (% difference between sides = 15.85%;  $F_{1,44} = 3.97$ ) with increased asymmetry in PD non-fallers compared to CG non-fallers (Fig. 2). There were no other main effects or interaction effects observed for this condition ( $p > 0.05$ ). In addition, there was a significant main effect of falls for people with PD. PD fallers presented faster anterior-posterior velocity than PD non-fallers ( $F_{1,22} = 4.04$ ,  $p = 0.049$ ). A significant main effect of limb was observed for people with PD, which indicated a higher total displacement of sway ( $F_{1,22} = 9.01$ ,  $p = 0.007$ ) in the most affected limb. A fall\*limb interaction was observed for people with DP with increased total displacement of sway ( $F_{1,22} = 5.57$ ,  $p = 0.022$ ) and vertical force ( $F_{1,22} = 5.27$ ,  $p = 0.032$ ) in most affected limb compared to least affected limb in PD non-fallers and increased anterior-posterior RMS ( $F_{1,22} = 5.01$ ,  $p = 0.030$ ) in most affected limb compared to least affected limb in PD fallers. For CG, the interaction indicated a reduction in anterior-posterior velocity of sway ( $F_{1,22} = 5.54$ ,  $p = 0.029$ ) in non-dominant limb compared to dominant limb in CG fallers. There were no main effects of limb for people with PD and CG, and fall for CG observed for raw CoP parameters ( $p > 0.05$ ).

For tandem – back leg condition, people with PD increased asymmetry of total displacement (% difference between sides = 4.53%;  $F_{1,44} = 4.81$ ) of sway compared to CG (Tables 2 and 3). A main effect of falls (% difference between sides = 4.22%;  $F_{1,44} = 4.18$ ), indicated that fallers had a decreased asymmetry of total displacement of sway compared to non-fallers. In addition, a group\*falls interaction indicated that PD non-fallers had increased asymmetry of total displacement (% difference between sides = 9.26%;  $F_{1,44} = 5.02$ ), anterior-posterior (% difference between sides = 7.70%;  $F_{1,44} = 4.06$ ) and medial-lateral (% difference between sides = 10.05%;  $F_{1,44} = 3.85$ ) RMS and medial-lateral mean velocity (% difference between sides = 13.38%;  $F_{1,44} = 7.45$ ) of sway in comparison to CG non-fallers (Fig. 2). Furthermore, PD non-fallers increased asymmetry of total displacement (% difference between sides = 9.85%) and medial-lateral RMS (% difference between sides = 9.54%) and mean velocity (% difference between sides = 11.01%) of sway compared to PD fallers. In addition, a fall \* limb interaction was observed for people with PD and CG. While the most affected limb presented faster medial-lateral velocity of sway ( $F_{1,22} = 5.54$ ,  $p = 0.029$ ) compared to least affected limb in PD fallers, dominant limb presented higher vertical force ( $F_{1,22} = 5.25$ ,  $p = 0.032$ ) compared to dominant limb in CG non-fallers. There were no main effects of fall and limb observed for raw CoP parameters in people with PD and CG ( $p > 0.05$ ).

#### 4. Discussion

In this study, we have compared the postural control asymmetry between fallers and non-fallers in people with PD and neurologically healthy individuals (CG) during side-by-side and semi-tandem standing. The current results demonstrated a significantly

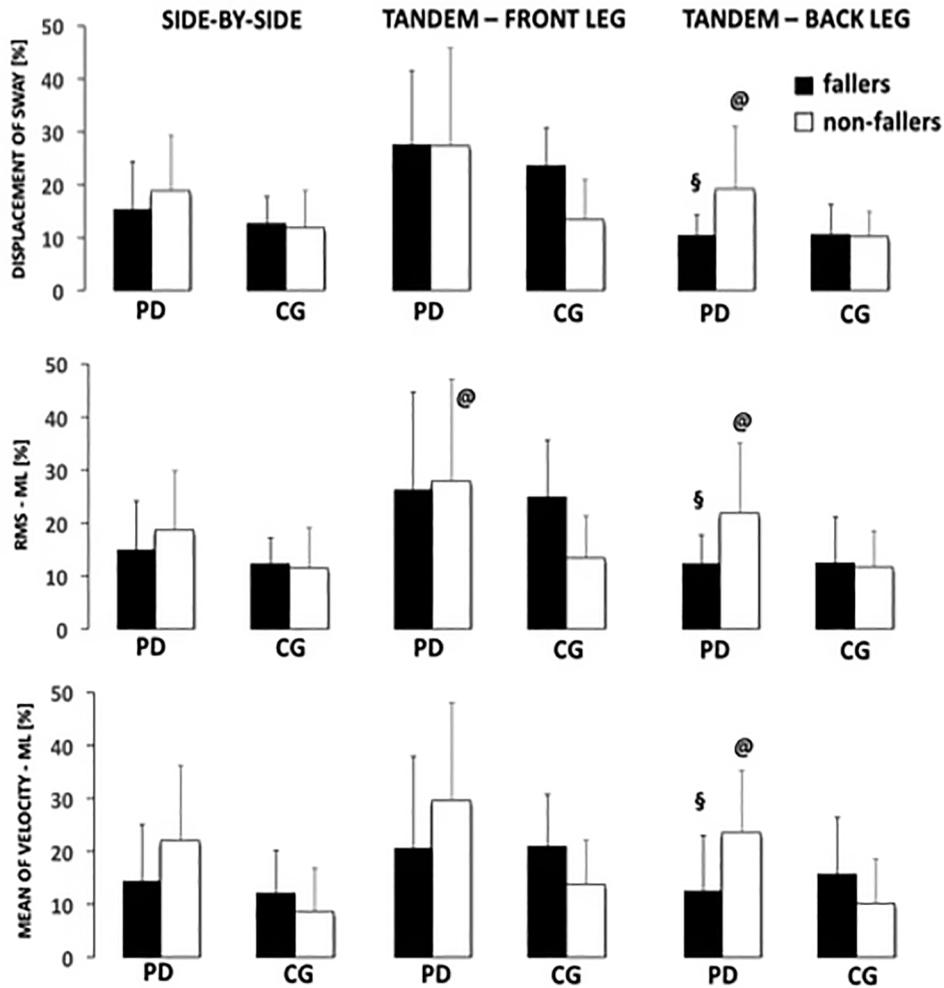


Fig. 2. Means and standard deviations of postural asymmetry index (first line: displacement of sway; second line: medial-lateral RMS; third line: mean velocity of sway) for three different stance tasks (first column: side-by-side; second column: tandem – front leg; third column: tandem – back leg), for fallers (black bars) and non-fallers (white bars), in the PD and control groups (CG). @ indicates significant post-hoc difference between PD vs. CG non-fallers; § indicates significant post-hoc difference between PD fallers vs. PD non-fallers.

greater postural asymmetry in individuals with PD compared to CG during the three different stance orientations, which confirmed our first hypothesis. This finding can be explained as the result of the “state” of asymmetry or “response” of asymmetry. State of asymmetry reflects the unilateral development of motor symptoms in PD caused by the asymmetric degeneration of dopaminergic neurons in the substantia nigra (Djaldetti et al., 2006). Response of asymmetry refers to an unequal compensatory response of the postural control system to improve balance, as observed in prior studies in PD (Barbieri et al., 2016; Beretta et al., 2015; Boonstra et al., 2016, 2014). This compensatory strategy is explained in the literature as an increased balance control contribution of the least affected limb, which canceled out the decreased balance control contribution of the most affected limb, resulting in generation of a sufficient amount of corrective torque (Boonstra et al., 2014). The use of this strategy is related to the increase in symmetry index. In addition, it is argued that the least affected limb compensated the most affected limb, possibly by increasing the common neural input (Boonstra et al., 2016). Neuroimaging studies in stroke patients (Grefkes & Fink, 2011) and an animal study with PD (Woodlee, Kane, Chang, Cormack, & Schallert, 2008) showed that unilateral impairment was related to enhanced functioning with reorganization and increased activation of the non-lesioned hemisphere. However, this approach of balance control asymmetry has not yet been investigated in PD fallers and non-fallers.

The current results did not support the hypothesis of the study that PD fallers are more asymmetric than PD non-fallers. Our results indicated that PD non-fallers had higher postural control asymmetry compared to PD fallers, especially during the semi-tandem-back leg condition. In addition, CoP changes suggest that the PD non-fallers use the most and least affected limbs differently. However, there was no asymmetry during side-by-side stance, which could be explained by no difference in UPDRS III between PD fallers and non-fallers and corroborated with previous studies (Beretta et al., 2015; Geurts et al., 2011). In addition, most evidence of postural control asymmetry was found in the tandem stance- back leg condition. In this condition, greater demand is placed on the

back leg to control balance, which supports the notion that postural asymmetry is augmented by higher task complexity (Beretta et al., 2015, 2018).

Asymmetric control, especially during tandem-stance, may be indicative of a more protective strategy, allowing for one foot to play a more dominant role in controlling balance, and/or preparing a potential step in case of a fall. Differences found in the CoP parameters between limbs confirmed that one foot plays a dominant role. One strategy to control postural asymmetry is to increase the stiffness of the one leg. A stiffening strategy is an attempt by the central nervous system to decrease body sway through increased muscular co-activation, reducing the risk of falling and improving weight support (Carpenter et al., 2004; Carpenter, Frank, & Silcher, 1999). For example, the individuals could reduce the sway of one leg (possibly least affected limb in our study), allowing the other leg to find a better strategy or adjustment to improve balance, which seems to cause asymmetry, but avoid falls. Therefore, our findings seem to suggest that “specializing” one leg for weight support and the other to control sway, may be a good strategy. This suggests that postural control asymmetry is an important compensatory mechanism, which may assist in avoiding falls in healthy individuals, and is further employed in people with PD in order to protect against a fall. From this perspective, asymmetric postural control may be a helpful strategy for reducing falls in challenging standing tasks, particularly in PD where the ability to rapidly switch between motor programs may be impaired (Weiss, Stelmach, & Hefter, 1997). However, this type of compensatory strategy is only speculated at this point and requires additional experiments to confirm if compensation really does help maintain balance. In addition, many situations in daily life require a good postural control of both limbs, which avoids a compensatory strategy to compensate the postural control asymmetry and can enhance the difficulty to control the posture.

Contrary to prior studies, a post-hoc analysis of the current results showed that the side of asymmetry was not predominantly towards the least affected limb, with only 50% of PD fallers and 50% of PD non-fallers having greater asymmetry toward the least affected limb. This matches the distribution in CG, in whom greater asymmetry toward the dominant limb was found in 50% of CG fallers and 75% of CG non-fallers. A possible explanation for the contradictory findings between this and prior studies is the method used to determine the least and most affected sides. While we have considered only clinical scores of the lower body, previous studies seem to have relied on clinical scores derived for the upper body to determine the least and most affected sides (2014; Barbieri et al., 2016; Beretta et al., 2015; Boonstra et al., 2016).

There are a number of potential limitations of this study. One potential limitation is our relatively small sample size considering the number of potential variables that could affect the asymmetry in postural control, such as disease duration, severity of disease, limb preference, etc. However, the number of participants in each group was greater than the sample size estimates we calculated based on prior results. Another potential limitation is our definition of a faller based on the occurrence of at least one fall within 12-months, without considering fall recurrence. Unfortunately, the classification of fallers lacks consensus in the literature. Therefore, the criterion used in this study could be considered a weak criterion to define falling individuals. Considering these limitations, our findings should be considered carefully.

## 5. Conclusion

The results supported the hypothesis that people with PD are more postural control asymmetries than neurologically healthy individuals. However, the results of the study did not support the hypothesis that PD fallers are more asymmetric than PD non-fallers. On the contrary, our results indicated that PD non-fallers had higher postural control asymmetry, especially during semi-tandem standing. Future studies should investigate the mechanic and neural functioning of postural control asymmetry in falling individuals, especially in challenging postural tasks.

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