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Utility of center of pressure measures during obstacle crossing in prediction of fall risk in people with Parkinson's disease

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ABSTRACT

Introduction: Postural instability during walking and tripping over obstacles are the main causes of falls in people with Parkinson's disease (PD). Preliminary limited evidence suggests that the length of the prospective follow-up period affects falls prediction in PD, with shorter periods leading to more accurate prediction. Thus, the primary aim of the present study was to test the performance of center of pressure (CoP) variables during obstacle crossing to predict fall risk in people with PD during subsequent periods of four, six, and 12 months. We also compared CoP variables during obstacle crossing between fallers and non-fallers.

Methods: Forty-two individuals with PD, in mild to moderate stages, completed the baseline obstacle crossing assessment and reported falls for 12 months. Participants walked at their self-selected pace and were instructed to cross an obstacle (half knee height) positioned in the middle of an 8-m long pathway. A force platform was used to analyze CoP parameters of the stance phase of the trailing limb (most affected limb). The ability of each outcome measure to predict fall risk at four, six, and 12 months was assessed using receiver operating characteristic curve analyses.

Results: Ten individuals (23.8%) were considered fallers at four months, twelve individuals (28.5%) at six months, and twenty-one individuals (50%) at 12 months. CoP amplitude and CoP velocity in the mediolateral direction significantly predicted fall risk at four, six, and 12 months. As judged by the area under the curve, mediolateral CoP velocity showed the best performance at four months, while mediolateral CoP amplitude showed the best performance at six months. Fallers presented greater values of mediolateral CoP velocity and amplitude than non-fallers.

Conclusion: These findings suggest that mediolateral CoP velocity and amplitude during obstacle crossing might be useful to predict fall risk in people with PD. Therefore, larger studies are encouraged.

1. Introduction

Postural instability marks the onset of the most disabling processes of Parkinson's disease (PD), and does not respond to conventional drug treatment (Curtze, Nutt, Carlson-Kuhta, Mancini, & Horak, 2015; Foreman et al., 2012). Unbalance presented by individuals with PD initially manifests as pro and retropulsive gait, inability to regain balance after external perturbation, and difficulties standing in a stationary position (Horak, Nutt, & Nashner, 1992). The consequence of these impairments is a high

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incidence of falls. A review paper showed that 60% of individuals with PD fell at least once during the previous 12 months, and 39% fell recurrently (Allen et al., 2013). The occurrence of falls is directly related to decreased quality of life, due to a series of clinical and social complications, such as: fractures, fear of future falls, and loss of independence in daily activities (Bloem, Grimbergen, Cramer, Willemsen, & Zwinderman, 2001; Melton et al., 2006). Fall-related complications also increase health costs (Australian Institute of Health and Welfare (AIHW), 2007) and the possibility of death (Thomas, Stevens, Sarmiento, & Wald, 2008).

The appropriate management of fall occurrence in PD requires the development of tools that can identify individuals at an imminent risk of falls, even before the first fall occurs. Previous studies identified that a history of previous falls, impaired balance, freezing of gait, decreased muscle strength, dementia, impaired gait, and greater severity of clinical symptoms are associated with a greater risk of falls in PD (Allcock et al., 2009; Bloem et al., 2001; Latt, Lord, Morris, & Fung, 2009; Lord et al., 2016; Paul et al., 2016; Pickering et al., 2007; Vitório et al., 2017). Although numerous risk factors for fall occurrence have been identified in PD, reliable predictors of future falls are still lacking and, therefore, additional research in this field is needed.

Loss of balance during locomotion and tripping over obstacles have been identified as major causes of falls in PD (Ashburn, Stack, Ballinger, Fazakarley, & Fitton, 2008; Vitório et al., 2017). As such, postural stability assessment during obstacle crossing might be beneficial for the completion of a possible fall risk assessment in PD. To date, obstacle crossing tasks have been shown to discriminate people with PD vs. healthy individuals (Galna, Murphy, & Morris, 2013; Vitório et al., 2013), mild vs. moderate PD (Vitório, Lirani-Silva, & Baptista et al., 2014; Vitório, Lirani-Silva, & Pieruccini-Faria et al., 2014), and individuals with balance disorders vs. healthy individuals (Hahn & Chou, 2003). Analysis of the center of pressure (CoP) represents a possible way to assess postural stability during locomotor tasks. Indeed, a recent study showed that CoP displacement during gait distinguished between faller and non-faller older adults (Svoboda et al., 2017). However, to the best of our knowledge CoP measures during obstacle crossing have never been investigated as a discriminator between PD fallers and non-fallers or as a predictor of falls in PD. Therefore, the current study was designed to explore these existing gaps.

Another important aspect that must be considered in the prediction of falls in PD is the length of the follow-up period. This has been investigated by only two previous studies. Duncan et al. (2012) showed that balance tests (i.e. BESTest, Mini-BESTest and Berg Balance Scale), presented better performance in predicting falls in PD within six months when compared to 12 months. Vitório et al. (2017) expanded the comparison and demonstrated that clinical (i.e. Unified Parkinson's Disease Rating Scale and Mini-Mental State Examination) and walking measures (i.e. spatiotemporal parameters of usual walking and obstacle crossing) were better predictors of falls in PD within four months when compared to six and 12 months. Considering that the influence of the length of the follow-up period in fall prediction in PD is insufficiently investigated, the current study also aimed to explore how the performance of CoP measures in predicting falls in PD changes as a function of the follow-up period.

The primary aim of the present study was to test the performance of CoP variables during obstacle crossing to predict fall risk in people with PD during subsequent periods of four, six, and 12 months. We also aimed to compare CoP variables during obstacle crossing between fallers and non-fallers. First, we hypothesized that the CoP variables would be able to predict fall risk and differentiate faller from non-faller individuals. More specifically, we expected that the mediolateral variables of CoP would show better performance than the anteroposterior variables, since mediolateral adjustments are more sensitive to maintenance of postural control during obstacle crossing than anteroposterior adjustments (Galna et al., 2013). Second, based on the findings of Duncan et al. (2012) and Vitório et al. (2017), we expected that the best performance of CoP variables for fall risk prediction in PD would be found in shorter follow up periods (four and six months).

2. Methods

2.1. Participants

All the experimental procedures were approved by the local ethics committee (Process #3439/2010). Forty-two individuals with PD participated in this study. Participants were recruited via local advertisement and from a database at the Posture and Gait Studies Laboratory at Sao Paulo State University in Rio Claro, Brazil. Patient diagnosis was confirmed by a neurologist. Exclusion criteria were: disease at a stage higher than 3 on the Hoehn & Yahr Rating Scale (H&Y), cognitive decline detected by the Mini Mental State Examination (MMSE – score < 24) (Brucki, Nitrin, Caramelli, Bertolucci, & Okamoto, 2003), use of walking aids (e.g., cane, walkers, etc.), and a history of orthopedic problems that made it impossible to complete the experimental protocol. For clinical and obstacle crossing assessments, participants were evaluated in the "ON" state of the specific medication of PD (between 45 and 60 min after drug intake). The most affected lower limb was defined as the one with more severe signs of PD in the following items of the Unified Parkinson's Disease Rating Scale (UPDRS): 20.4, 20.5, 22.4, 22.5, 26.1, and 26.2.

2.2. Clinical evaluation

The motor impairments of PD were assessed by the Unified Parkinson's Disease Rating Scale part III (UPDRS III; Fahn & Elton, 1987). Individual items are rated from 0 (normal) to 4 (severe) with a maximum score of 108 points. The H&Y scale was used to classify the participants according to disease stages, which vary from 1 (unilateral involvement only usually with minimal or no functional disability) to 5 (confinement to bed or wheelchair unless aided). For the purpose of cognitive screening, the MMSE was applied.

2.3. Obstacle crossing

Participants were invited to walk at a self-selected pace along a pathway (8 m long by 1.4 m wide) and cross an obstacle positioned in the middle of the pathway. The obstacle was made of foam (3 cm depth × 60 cm width), and the height was determined for each participant using half knee height (Pieruccini-Faria et al., 2013). A force platform (AccuGait, Advanced Mechanical Technologies, Boston, MA) – 50 cm × 50 cm, 200 Hz – was positioned immediately before the obstacle to record the ground reaction forces of the trailing limb stance phase. In order to avoid additional variability in the data caused by potential side differences while performing the task (Barbieri et al., 2018), participants were instructed to cross the obstacle using the less affected limb as the leading limb. Three trials were analyzed. The raw data were filtered using a low-pass, 2nd-order digital Butterworth filter, with a cut-off frequency of 16 Hz, in MATLAB environment. The stance phase was determined as the time interval during which the vertical ground reaction force exceeded 10% of the participant's body weight (measured using the same force plate as at the beginning of the protocol). The following CoP variables were calculated: amplitude and velocity in anteroposterior and mediolateral directions.

2.4. Occurrence of falls evaluation

The definition of a fall considered in this study was as unintentionally coming to the ground or some lower level not as a result of a major intrinsic event (e.g., stroke) or overwhelming hazard (Kerr et al., 2010). A weekly prospective follow-up, through personal interview and/or telephone contact, was used to evaluate the occurrence of falls during the 12 months following the obstacle crossing evaluation. Participants who presented one or more falls were classified as fallers. Those classified as fallers in shorter periods were also classified as fallers in longer periods. UPDRS item #13 (i.e. self-reported falls in the previous 12 months) is reported to characterize participants' history of falls (before the baseline assessment).

2.5. Statistical analysis

Descriptive statistics (mean ± standard deviation) were used to present the demographic variables, which were compared between groups using unrelated sample t-tests and Mann-Whitney tests. The distribution of the dependent variables was tested using Shapiro-Wilk test. Afterwards, independent sample t-tests and Mann-Whitney tests were used to compare CoP amplitude and velocity in the anteroposterior and mediolateral directions between fallers and non-fallers in each period of interest. Receiver operating characteristic (ROC) curve analysis was used to test the performance of CoP amplitude and velocity in the anteroposterior and mediolateral directions in predicting fall risk in subsequent periods of four, six, and 12 months in people with PD. The values of sensitivity (i.e., the proportion of positive cases that are correctly identified as such), specificity (i.e., the proportion of negative cases that are correctly identified as such), and area under the curve (a measure of overall accuracy of a diagnostic test or predictor) were calculated. The cut-off point was determined through an algorithm that identified the closest point of the curve to the ideal point (sensitivity and specificity equal to 1). The time point (four, six, and 12 months) that consistently produced dependent variables with best values for area under the curve was interpreted as the most accurate time point. The significance level was set at 0.05 for all analyzes and SPSS 22.0 (SPSS, Inc.) was used for statistical treatment.

3. Results

Table 1 shows the clinical and anthropometric characteristics of our sample for fallers and non-fallers in the periods of four, six and 12 months. It is important to highlight that individuals included in the analysis showed mild to moderate disease severity (UPDRS motor section) and the majority were in stages 1–2 on the Hoehn & Yahr Rating Scale. Also, with regards to UPDRS item #13, 73.8% of the participants reported no falls and 26.2% reported at least one fall in the previous 12 months (before the baseline assessment). Regarding the prospective assessment of falls, ten individuals (23.8%) were considered fallers at four months (with a total of 23 falls), twelve individuals (28.5%) were considered fallers at six months (with a total of 40 falls), and twenty-one individuals (50%) were considered fallers at twelve months (with a total of 64 falls).

Table 2 presents the values obtained in the ROC analysis on the performance of classifiers in the prediction of fall risk in PD in the subsequent periods of four, six, and 12 months. CoP variables that demonstrated significant prediction of fall risk were CoP amplitude and velocity in the mediolateral direction at four, six, and 12 months (Fig. 1; Table 2). Mediolateral CoP velocity consistently demonstrated better values of sensitivity and area under the curve when compared to mediolateral CoP amplitude (Fig. 1; Table 2). In addition, mediolateral CoP velocity presented the best performance at four months, while mediolateral CoP amplitude presented the best performance at six months (as judged by area under the curve; Table 2).

Table 3 shows the means and standard deviations of the CoP variables for fallers and non-fallers in the periods of four, six, and 12 months. The Student's *t* test and Mann-Whitney test showed significant differences for CoP variables. For all periods, there was a significant difference in CoP amplitude and velocity in the mediolateral direction, with fallers presenting greater values compared to non-fallers. At four months, fallers demonstrated significantly smaller anteroposterior CoP amplitude than non-fallers.

4. Discussion

This study primarily aimed to test the performance of CoP variables during obstacle crossing to predict fall risk in people with PD during subsequent periods of four, six, and 12 months. CoP amplitude and velocity in the mediolateral direction were identified as

Table 1
Characteristics of the individuals with PD.

Demographic measure	Sample	4 months			6 months			12 months		
		Faller	Non-faller	*p*	Faller	Non-faller	*p*	Faller	Non-faller	*p*
Female/Male	19/23	06/04	13/19	–	08/04	11/19	–	09/12	10/11	–
Age (years)	65.59 ± 9.22	65.80 ± 6.16	65.53 ± 10.08	0.937	65.67 ± 4.74	65.57 ± 10.58	0.975	64.81 ± 7.55	66.38 ± 10.98	0.587
Body mass (kg)	72.02 ± 11.43	70.27 ± 14.11	72.57 ± 10.67	0.585	71.31 ± 13.70	72.66 ± 10.59	0.577	70.49 ± 11.53	73.56 ± 11.40	0.391
Body height (cm)	161.86 ± 9.54	157.73 ± 10.0	163.16 ± 9.17	0.118	157.50 ± 11.3	163.61 ± 8.31	0.060	161.53 ± 11.1	161.19 ± 7.95	0.828
UPDRS #13 (0/1/2)	31/9/2	3/6/1	28/3/1	–	4/7/1	27/2/1	–	11/9/1	20/0/1	–
UPDRS-III (0–108)	20.28 ± 7.93	19.20 ± 8.88	20.41 ± 7.50	0.673	20.42 ± 9.04	20.00 ± 7.35	0.877	19.81 ± 7.26	20.43 ± 8.39	0.800
UPDRS total (0–176)	34.95 ± 11.74	34.9 ± 14.28	34.72 ± 10.16	0.965	36.92 ± 12.99	33.90 ± 10.34	0.432	36.14 ± 11.15	33.38 ± 11.11	0.426
MMSE (0–30)	27.88 ± 2.12	27.90 ± 1.45	27.88 ± 2.31	0.716	28.17 ± 1.64	27.77 ± 2.30	0.758	28.38 ± 1.63	27.38 ± 2.96	0.745
H&Y (stage: 1/1.5/2/2.5/3)	11/20/8/2/1	3/6/0/0/1	8/14/8/2/0	0.975	4/4/3/0/1	7/16/5/2/0	0.587	6/10/4/0/1	5/10/4/2/0	0.128

UPDRS: *Unified Parkinson's Disease Rating Scale*; MMSE: Mini Mental State Examination; H&Y: Hoehn & Yahr scale.

Table 2
Values of the ROC analysis on the performance of CoP variables in predicting fall risk in people with PD in subsequent periods of four, six and 12 months.

CoP Variables	4 months				6 months				12 months			
	p	Cut-off point	Se/Sp	AUC	p	Cut-off point	Se/Sp	AUC	p	Cut-off point	Se/Sp	AUC
Amplitude_AP	ns	–	–	–	ns	–	–	–	ns	–	–	–
Amplitude_ML	0.021	5.83 cm	0.700/0.812	0.744	0.008	4.82 cm	0.833/0.700	0.764	0.028	4.37 cm	0.667/0.667	0.698
Velocity_AP	ns	–	–	–	ns	–	–	–	ns	–	–	–
Velocity_ML	0.002	5.3 cm/s	0.900/0.750	0.834	0.002	4.65 cm/s	0.917/0.667	0.803	0.012	4.14 cm/s	0.810/0.571	0.726

AP: anteroposterior direction; ML: mediolateral direction; Se: sensitivity; Sp: specificity; AUC: area under the curve; ns: not significant.

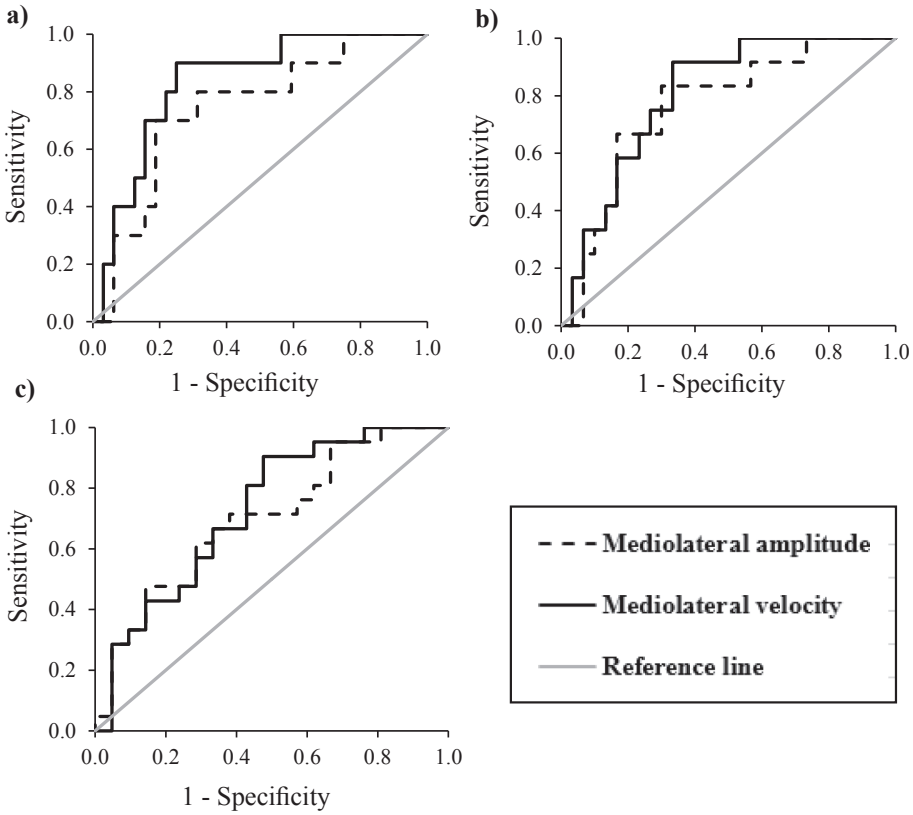

Fig. 1. ROC curves for the significant predictors identified at four months (a), six months (b) and twelve months (c).

Table 3
Averages, standard deviations, and differences in CoP variables between fallers and non-fallers patients in the 4, 6, and 12-month periods.

Period	Variable	Faller	Non-faller	p	T	z
4 months	Amplitude_AP (cm)	17.07 ± 2.88	18.97 ± 2.00	0.024	2.34	–
	Amplitude_ML (cm)	6.13 ± 1.72	4.44 ± 1.81	0.021	–	2.30
	Velocity_AP (cm/s)	20.13 ± 5.13	19.72 ± 4.10	ns	–	–
	Velocity_ML (cm/s)	6.96 ± 1.77	4.56 ± 1.97	0.001	−3.42	–
6 months	Amplitude_AP (cm)	17.71 ± 3.05	18.85 ± 1.97	ns	–	–
	Amplitude_ML (cm)	6.12 ± 1.64	4.33 ± 1.79	0.008	–	2.64
	Velocity_AP (cm/s)	19.74 ± 5.22	19.85 ± 3.98	ns	–	–
	Velocity_ML (cm/s)	6.61 ± 1.79	4.54 ± 2.04	0.004	−3.07	–
12 months	Amplitude_AP (cm)	17.94 ± 2.53	19.10 ± 2.05	ns	–	–
	Amplitude_ML (cm)	5.53 ± 1.89	4.16 ± 1.70	0.028	–	2.20
	Velocity_AP (cm/s)	19.63 ± 4.41	20.00 ± 4.29	ns	–	–
	Velocity_ML (cm/s)	5.89 ± 2.00	4.37 ± 2.10	0.021	−2.40	–

AP: anteroposterior direction; ML: mediolateral direction; ns: not significant.

significant predictors of fall risk in PD at four, six, and 12 months. Mediolateral CoP velocity presented the best performance at four months, while mediolateral CoP amplitude showed the best performance at six months. These findings are in line with our hypothesis that CoP variables in the mediolateral direction, rather than those in the anteroposterior direction, would be able to better predict fall risk in PD. Additionally, our second hypothesis was also confirmed as shorter periods (four and six months) showed better accuracy than 12 months for fall risk prediction in PD.

Previous experimental studies have shown that stepping over obstacles is a challenging task for people with PD, accentuating patient postural instability (Galna, Murphy, & Morris, 2010; Galna et al., 2013). Indeed, more severe motor symptoms in people with PD (measured using the UPDRS motor section) are associated with faster sideways sway during obstacle crossing (Galna et al., 2013) and shorter foot to obstacle distances (Vitório, Lirani-Silva, & Baptista et al., 2014; Vitório, Lirani-Silva, & Pieruccini-Faria et al., 2014). As a consequence, people with PD also increase their step width, which indicates a possible compensation strategy used to overcome postural instability in the mediolateral direction during obstacle crossing (Galna et al., 2010). Our findings are in line with this interpretation as fallers showed greater adjustments in the mediolateral direction than non-fallers (Table 3). In addition, our findings corroborate with those reported by Svoboda and colleagues (Svoboda et al., 2017), who showed that CoP displacement during gait distinguished between faller and non-faller older adults.

The length of follow-up period influences the prediction of fall risk in PD. Our results indicated that the best accuracy for fall risk prediction in PD, while using CoP variables during obstacle crossing, were observed at four and six months (instead of at 12 months). These results suggest that the predictive ability of the initial assessment is compromised in longer follow-up periods due to the progressive aspect of PD. It is possible that individuals classified as fallers at 12 months, who were not classified as fallers at four and six months, demonstrated good performance in the initial obstacle crossing assessment. Those who performed well in the initial assessment, and were classified as fallers only in the 12-month period, act as confounders in the analyses of fall risk prediction that considers 12 months of follow-up. Current findings are consistent with a previous study which investigated the influence of the length of the follow-up period on the performance of classifiers to predict falls in PD (Duncan et al., 2012). Therefore, it is possible to suggest that people with PD should be assessed every 4 or 6 months to detect the possibility of becoming fallers.

It is important to consider how well the predictors identified in the current study perform when compared to previously reported predictors. One consistent finding across previous studies is that the best predictor of a future fall in people with PD is a previous fall (Pickering et al., 2007). This provides very limited information as previous falls cannot be used for the prediction of the very first fall, which should be the ultimate aim of research in this field. Additionally, self-report of falls over long periods (which is the case for UPDRS item #13) has many flaws, such as the underestimation of falls. For example, Garcia, Dias, Silva, and Dias (2015) observed that self-reporting of falls over a 12-month period underestimated 32.8% of falls and 50% of recurrent falls (compared to prospective monitoring via phone calls over the same period). We have run similar ad hoc ROC curve analysis to inform readers regarding how the predictive value of CoP variables compares with UPDRS item #13 (history of falls in the last 12 months before the baseline assessment). Although significant in all three moments, UPDRS item #13 showed lower values of sensitivity (4 months: sensitivity = 70%; 6 months: sensitivity = 66.7%; 12 months: sensitivity = 47.6%) when compared to CoP variables (e.g. CoP velocity in ML direction: 90%, 91.7% and 81%, respectively). These findings suggest that UPDRS item #13 has much lower predictive ability than CoP variables and therefore caution is recommended when considering self-reported falls over long periods.

Other good predictors of falls in PD include the combination of clinical tests and/or instrumented assessment. For example, Kerr et al. (2010) reported that the combination of the UPDRS total score, total freezing of gait score, occurrence of symptomatic postural orthostasis, Tinetti total score, and extent of postural sway in the anterior-posterior direction produced a sensitivity of 78% and specificity of 84%, with overall accuracy (area under the curve) of 0.807 (Kerr et al., 2010). Paul et al. (2013) showed that a positive fall history, a history of freezing of gait, and reduced gait speed (< 1.1 m/s) presented overall accuracy of 0.80 (Paul et al., 2013). In the current study, the single measure of mediolateral CoP velocity during the trailing limb stance phase produced a slightly better predictive performance (at four months): sensitivity of 90% and specificity of 75%, with overall accuracy of 0.834. Therefore, it seems reasonable to further explore the potential of mediolateral CoP velocity during the trailing limb stance phase to predict falls in PD. As this predictor has high sensitivity, we suggest that the next step should be to test combinations with high-specificity predictors.

4.1. Limitations and future directions

It is important to highlight that approximately 93% of our sample had mild PD (stages 1–2 on the Hoehn and Yahr Rating Scale) and that all the participants were community-dwelling individuals. Therefore, the generalizability of the current findings is limited. A second limitation is the small sample size and, therefore, we acknowledge the pilot nature of this work. Despite this major limitation, findings are new in the literature and highlight the potential utility of CoP measures recorded during obstacle crossing in predicting fall risk in PD. In light of the positive findings, current methods should be explored in studies with larger samples in order to confirm whether they are eligible for the translation to clinical practice. Combinations with good predictors described in the literature should also be considered. Although financial investment would be necessary to buy a force plate, it is relatively easy to obtain CoP measures during an obstacle crossing task. Compared to other kind of movement analyses (e.g. kinematics, accelerometry, etc.), analysis of ground reaction forces has the advantage of not requiring the attachment of any markers or devices (e.g. accelerometers) to the participant. Additionally, the calculation of CoP variables could be easily implemented within a software or app, providing health professionals with accurate measures immediately after the assessment.

5. Conclusion

In conclusion, mediolateral CoP velocity and amplitude during obstacle crossing might be useful to predict fall risk in people with PD. The predictive ability of the initial obstacle crossing assessment achieved best accuracy in shorter follow-up periods (four and six months). Finally, CoP variables seem to be sensitive in discriminating between faller and non-faller individuals with PD.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.humov.2019.03.010.

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