Standing balance in individuals with Parkinson's disease during single and dual-task conditions

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Abstract

This study aimed to examine the differences in standing balance between individuals with Parkinson's disease (PD) and subjects without PD (control group), under single and dual-task conditions. A cross-sectional study was designed using a non-probabilistic sample of 110 individuals (50 participants with PD and 60 controls) aged 50 years old and over. The individuals with PD were in the early or middle stages of the disease (characterized by Hoehn and Yahr as stages 1–3). The standing balance was assessed by measuring the centre of pressure (CoP) displacement in single-task (eyes-open/eyes-closed) and dual-task (while performing two different verbal fluency tasks).

No significant differences were found between the groups regarding sociodemographic variables. In general, the standing balance of the individuals with PD was worse than the controls, as the CoP displacement across tasks was significantly higher for the individuals with PD ($p < 0.01$), both in anteroposterior and mediolateral directions. Moreover, there were significant differences in the CoP displacement based parameters between the conditions, mainly between the eyes-open condition and the remaining conditions. However, there was no significant interaction found between group and condition, which suggests that changes in the CoP displacement between tasks were not influenced by having PD.

In conclusion, this study shows that, although individuals with PD had a worse overall standing balance than individuals without the disease, the impact of performing an additional task on the CoP displacement is similar for both groups.

Graphical abstract

Estimated marginal means and standard errors of the centre of pressure (CoP) based parameters in each condition and for the individuals with Parkinson's disease (PD) and controls.

Keywords

Centre of pressure; Dual-task; Parkinson's disease; Single-task; Standing balance

1. Introduction

Parkinson's disease (PD) is a chronic, progressive and neurodegenerative disorder affecting over 4 million people worldwide [1] and [2]. Its symptoms can be categorized as motor and non-motor. The four cardinal features of the disease are motor: tremor at rest, rigidity, bradykinesia and postural instability [3].

The postural instability impairs the ability to maintain standing balance during everyday activities and increases the risk of falling. This ability depends on the integrated functioning of proprioceptive, vestibular and visual systems, muscle properties and neural control [4]. The preservation of standing balance relies upon the ability to keep the body's centre of mass inside the base of support [5]. The corrective forces that control the centre of mass are usually measured by assessing the centre of pressure (CoP) displacement, which represents the point of application of all the ground reaction forces. Therefore, the CoP is commonly examined to detect subtle changes in standing balance [6].

Individuals with PD frequently resort to attentional strategies to maintain the postural stability and standing balance, due to the difficulty in achieving automaticity [7]. Consequently, several studies [8], [9] and [10] have shown that these individuals have serious difficulties in processing simultaneous tasks adequately. In fact, when two tasks are performed at the same time by the individuals, the competition for limited resources results in dual-task interference and deterioration in the performance of one or both tasks. This further impairs the ability of the individuals to perform everyday activities [1] and [10].

As the dual-task interference on standing balance depends on the nature and complexity of the secondary task [11], researchers should focus on examining which tasks significantly affect this ability in individuals with PD. Consequently, this study aimed to analyze the differences in the standing balance between individuals with PD and without PD (control group), under single and dual-task conditions. Furthermore, the impact of performing an additional task on the standing balance was compared.

2. Methods

2.1. Study design and participants

A cross-sectional study was designed using a non-probabilistic sample of 50 individuals with PD and 60 controls. The individuals diagnosed with PD were from the São Sebastião Hospital, Santa Maria da Feira, in Portugal, and had been referred by their neurologist. These participants were 50 years old and over as in a previous research that has shown that the prevalence of this disease is significantly higher in this age group [12]. Consequently, in order to reduce the probability of having significant differences between the groups due to age, only individuals 50 years old or more were included in the control group. The control group was made up of community-dwelling subjects without PD that volunteered after information regarding the study was disclosed in community institutions, like social, recreation and day care centres, in Porto, Portugal.

The exclusion criteria were severe cognitive impairment, screened using the Mini Mental State Examination (MMSE) [13]. This exam used the following cut-off points: ≤22 for 0–2 years of literacy; ≤24 for 3–6 years; and ≤27 for ≥7 years, which are based on the normative values for Portuguese older adults [14] as its performance varies within the population according to the education level. Individuals that could not stand upright, walk short distances without assistance, unable to speak Portuguese were also excluded. Further exclusion criteria for individuals with PD were severe disability (>3 on the Modified Hoehn and Yahr Scale [15]), additional diagnosis of neuromuscular disease, and history of deep brain stimulation through subthalamic surgery. Controls that self-reported any neuromuscular disease were also excluded. However, taking into account that these individuals were community-dwelling individuals that volunteered to participate in the study, their medical doctor was not consulted. A trained researcher conducted the data collection, using a structured protocol. The individuals with PD were assessed in the São Sebastião Hospital and in the Portuguese Parkinson's Association in Porto. The controls were evaluated in the local community institutions through which they had first been contacted in order to be included in the study.

The study was approved by all the Institution's Ethical Review Boards and written informed consent, according to the Helsinki Declaration, was obtained from all participants.

2.2. Measurements

The data collected from all participants included sociodemographic characteristics (age, sex and level of education), use of a walking aid, body mass index (BMI), cognitive performance (assessed with MMSE [13]), standing balance in single and dual-tasks (examined by measuring of the CoP displacement using a pressure platform (Emed-AT25 D, from Novel Inc., Munich, Germany)), and number of words enunciated in the dual-task condition. The Modified Hoehn and Yahr Scale [15] and part III of the Unified Parkinson's Disease Rating Scale (UPDRS) [16] were also used to determine the severity of the impairment regarding the motor function of the individuals with PD. The latter information was provided by the individuals' neurologists immediately before the evaluation conducted in this study.

The participants' standing balance, both under single- and dual-task conditions, was assessed with a pressure platform, containing 4000 capacitive sensors within a sensing area of 380 × 240 mm^2 (sensor resolution of 3 sensors/cm^2), capable of acquiring the individual's plantar distribution, both in a static or dynamic form, as well as obtaining stabilometric measures, such as the CoP. Following previous studies [17] and [18], the CoP displacement based parameters studied were its maximum displacement (cm) in the anteroposterior (AP) and mediolateral (ML) directions, and its mean velocity (cm/s). For this measurement, each subject was asked to take off his/her shoes, step onto the platform, and maintain an orthostatic position for 60 s. The standing balance under single-task condition was assessed in two tasks: with eyes open (looking at a target placed two metres away at the height of the participants' eyes) and with eyes closed. In order to examine the standing balance under dual-task conditions, the participants were asked to maintain an upright standing position while performing two different verbal fluency tasks: semantic fluency task (enunciate the name of as many species of animals as possible) and phonemic fluency task (enunciate as many words as possible beginning with the letter R). These verbal fluency tasks were adapted from a previous study [19]. The order of each test changed randomly, from individual to individual, in order to avoid a learning effect and fatigue. The CoP based parameters were further analyzed considering the most stable 30-second period of each test.

The UPDRS [16], which was developed to monitor multiple aspects of PD related to disability and impairment, is made up of four parts, and is the most widely used scale for multicentre clinical trials in PD. Furthermore, this assessment tool has a satisfactory interrater reliability. Only the part III of the UPDRS scale was used in this study for the motor examination. The score given for each item varies from 0 to 4, from normal to severe; and the part III total score ranged from 0 to 52. This scale is often accompanied by the Modified Hoehn and Yahr Scale [15], which evaluates the severity of overall dysfunction in PD. This is a 7-point scale, in which each point is a different stage of the disease (stages 1–5, including 1.5 and 2.5). The scale increases with the severity of dysfunction along with the stage of the disease. All tests were carried out with the participants taking their prescribed medications, and were therefore denoted as "ON" medication, as in others studies [10] and [20].

2.3. Statistical analysis

According to the nature of the variables under study, descriptive statistical analyses were performed using proportions and measures of central tendency and dispersion.

Independent samples *t* test and chi-square test were performed to examine whether there were significant differences between the individuals with PD and the controls, for the sociodemographic variables, BMI, use of walking aid, MMSE score, number of words enunciated in each verbal fluency task. The correlation of the CoP based parameters with age and with the amount of words enunciated in the verbal fluency tasks were also examined using the Pearson correlation.
A mixed model (between-within) ANOVA analysis of variance was conducted to ascertain if any change in the CoP displacement between tasks is different across groups (PD × controls), i.e. if there is an interaction effect. The differences in CoP based parameters between tasks (within-subjects) and between groups (between-subjects) were also analyzed separately. The Bonferroni post hoc analysis was used as a post hoc test to determine between which tasks there were significant differences.

Two-tailed tests were used in all analyses and a p-value <0.05 was adopted for statistical significance. All statistical analyses were conducted using IBM SPSS Statistics 22.0 (SPSS, Inc., Chicago, IL, USA).

3. Results

The PD sample comprised 50 subjects (62% male), with a mean age of 68.3 years old (SD = 7.3) and a mean education of 5.2 years (SD = 3.9). Most participants were classified in stage 2 of the Modified Hoehn and Yahr Scale, and had a mean UPDRS score of 19.1 (SD = 7.9). The control sample comprised 60 individuals (56.7% male), with a mean age of 68.9 years old (SD = 10.1), and mean education of 5.8 years (SD = 3.8). Independent samples *t* test and chi-square test showed no statistically significant differences between samples, concerning the sociodemographic variables, BMI, use of walking aid, MMSE score, and number of words enunciated in each verbal fluency task, Table 1.

Table 1
Comparison of both groups regarding the sociodemographic variables, body mass index (BMI), use of walking aid, Mini-Mental State Examination (MMSE) score, and number of words enunciated in each verbal fluency task.

	Individuals with PD (n = 50)	Controls (n = 60)	p-Value
	M (SD)	M (SD)	
Age (years)	68.3 (7.3)	68.9 (10.1)	0.72*
Gender (male), n (%)	31 (62)	34 (56.7)	0.70**
Education (years)	5.2 (3.9)	5.8 (3.8)	0.47*
BMI (kg/cm^2)	26.7 (4.2)	27.5 (4.0)	0.32*
MMSE	27.0 (1.9)	26.4 (3.7)	0.31*
Use of walking aid, n (%)	7 (14)	9 (15)	1.00**
UPDRS	19.1 (7.9)	–	–
Modified Hoehn and Yahr Scale			
Stage 1, n (%)	3 (6)	–	–
Stage 1.5, n (%)	8 (16)	–	–
Stage 2, n (%)	26 (52)	–	–
Stage 2.5, n (%)	9 (18)	–	–
Stage 3, n (%)	4 (8)	–	–
Verbal fluency tasks			
Semantic task	12.3 (3.8)	11.9 (4.5)	0.55*
Phonemic task	6.5 (2.9)	6.2 (4.3)	0.67*

Modified Hoehn and Yahr Scale: Stage 1 – unilateral disease; Stage 1.5 – unilateral and axial disease; Stage 2 – bilateral disease without impairment of balance; Stage 2.5 – mild bilateral disease; Stage 3 – mild to moderate bilateral disease.
* Independent samples t-test.
** Chi-square test.

No significant association was found between the CoP based parameters and the age ($0.38 < p < 0.99$ and $-0.08 < r < 0.08$) and also between the CoP based parameters and the amount of words enunciated in the verbal fluency tasks (semantic fluency task: $0.18 < p < 0.98$ and $-0.08 < r < 0.13$; phonemic fluency task: $0.07 < p < 0.64$; $-0.17 < r < -0.05$). Consequently, these variables were not included as covariates in further analyses.

Through the mixed model ANOVA (Table 2) analyses, it was possible to ascertain that there were statistically significant differences ($p < 0.01$) between the individuals with PD and the controls regarding the maximum CoP displacement (both in AP and ML directions), but not in regard to the mean CoP velocity ($p = 0.19$). Overall, the CoP based values were higher for the individuals with PD (Table 3).

Table 2
Results of the mixed model (between-within) ANOVA analysis of variance for each CoP based parameter.

CoP parameter	Effect	*p*-Value
Maximum CoP displacement in ML direction	Group (between-subject)	<0.01
	Condition (within-subjects)	<0.01
	Interaction	0.11
Maximum CoP displacement in AP direction	Group (between-subject)	<0.01
	Condition (within-subjects)	0.03
	Interaction	0.32
Mean CoP velocity	Group (between-subject)	0.19
	Condition (within-subjects)	<0.01
	Interaction	0.65

Table 3
Comparison of estimated marginal means of the CoP based parameters between groups.

CoP parameters	Controls		Individuals with PD		*p*-Value
	M (SE)	95%CI	*M* (SE)	95%CI	
Maximum CoP displacement in ML direction (cm)	1.87 (0.16)	1.54; 2.19	2.55 (0.18)	2.19; 2.90	<0.01
Maximum CoP displacement in AP direction (cm)	2.11 (0.12)	1.88; 2.34	2.59 (0.13)	2.34; 2.84	<0.01
Mean CoP velocity (cm/s)	1.01 (0.09)	0.90; 1.27	1.27 (0.10)	1.06; 1.47	0.19

Significant differences were also found between the tasks (within-subjects) for the maximum CoP displacement in ML direction ($p < 0.01$), maximum CoP displacement in AP direction ($p < 0.05$), and mean CoP velocity ($p < 0.01$). Post hoc analysis (Table 4) showed that these differences were between the eyes-open task and the remaining tasks, particularly for the maximum CoP displacement in ML direction and for the mean CoP velocity, and between the eyes-open and the eyes-closed conditions, in particular, for the maximum CoP displacement in AP direction.

Table 4
Comparison of estimated marginal means differences of the CoP based parameters between conditions.

Tasks		Maximum CoP displacement in ML direction (cm)			Maximum CoP displacement in AP direction (cm)			Mean CoP velocity (cm/s)		
		M (SE)	95%CI	*p*-Value	*M* (SE)	95%CI	*p*-Value	*M* (SE)	95%CI	*p*-Value
EO	EC	−0.27 (0.09)	−0.52; −0.03	<0.05	−0.39 (0.09)	−0.62; −0.16	<0.001	−0.27 (0.03)	−0.36; −0.18	<0.01
	SF	−0.63 (0.19)	−1.14; −0.13	<0.01	−0.36 (0.15)	−0.78; 0.05	0.12	−0.38 (0.09)	−0.63; −0.14	<0.01
	PF	−0.65 (0.19)	−1.15; −0.14	<0.01	−0.23 (0.13)	−0.59; 0.13	0.51	−0.34 (0.10)	−0.60; −0.09	<0.01
EC	SF	−0.36 (0.21)	−0.93; 0.21	0.53	0.03 (0.16)	−0.41; 0.47	1.00	−0.11 (0.10)	−0.38; 0.16	1.00
	PF	−0.38 (0.21)	−0.95; 0.20	0.50	0.16 (0.14)	−0.20; 0.53	1.00	−0.07 (0.10)	−0.35; 0.21	1.00
SF	PF	−0.01 (0.10)	−0.27; 0.25	1.00	0.13 (0.09)	−0.12; 0.38	0.94	0.04 (0.03)	−0.05; 0.13	1.00

EO, eyes-open task; EC, eyes-closed task; SF, semantic fluency task; PF, phonemic fluency task.

On the other hand, no significant interaction was found between group and task, which seems to indicate that the differences in the CoP displacement between tasks were similar for both groups. Therefore, it was found that the effect of performing a more complex task (standing with eyes closed), or an additional task (enunciating words while standing), on standing balance was not significantly different between the individuals with PD and controls (Fig. 1).

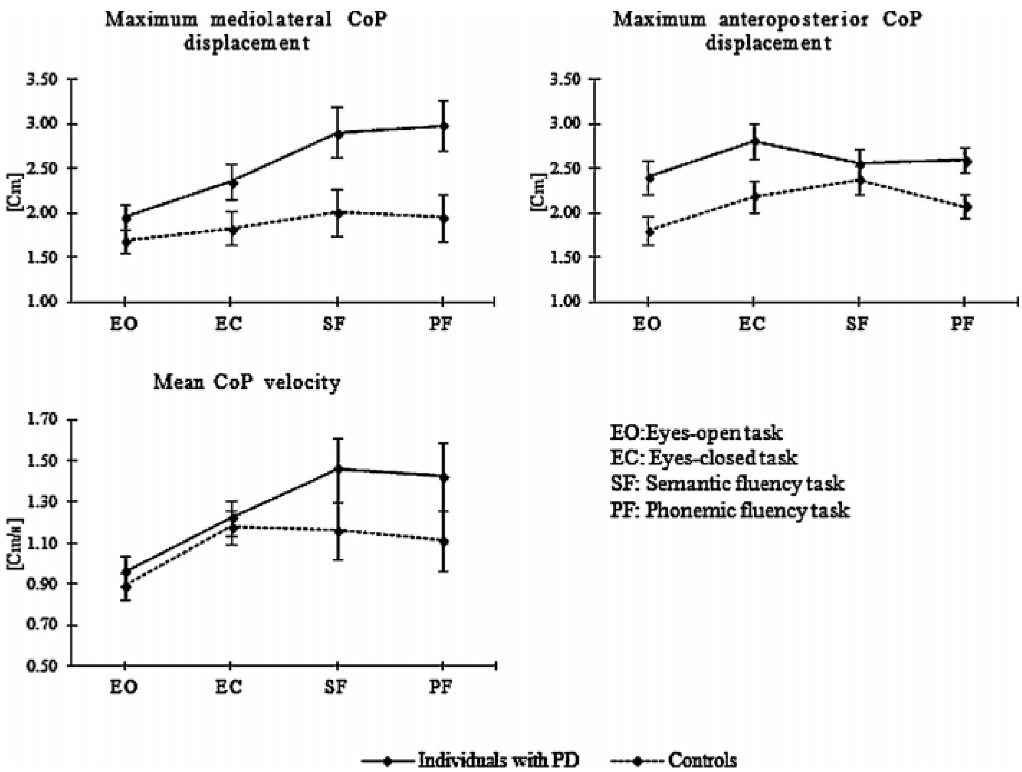

Fig. 1. Estimated marginal means and standard errors of the CoP based parameters in each condition and for each group.

4. Discussion

In general, the standing balance of the individuals with PD was worse (i.e. presented higher CoP displacement values) than those without the disease. For both groups, considering the selected CoP based parameters, the standing balance with eyes closed and under dual-task conditions was worse than the standing balance with eyes open. Furthermore, the differences in standing balance between tasks were not influenced by having PD. In other words, the impact of performing more complex tasks on standing balance was similar for the individuals with PD and the controls, although the standing balance of the individuals with PD was consistently worse.

In comparison with the controls, the individuals with PD had an increased difficulty in maintaining the standing balance. Although only early or middle severity PD individuals were included in the present study, these findings were reasonable considering that postural instability may occur in the early stages of PD [2] and [21]. Concomitantly, the CoP based values observed were similar to the ones found in previous studies [4], [21] and [22].

Also as expected, the standing balance was worse when the participants were requested to close their eyes or to perform an additional task. The visual system provides the central nervous system continuous information about the position of the body relative to the environment. Indeed, studies indicate that the postural stability increases with an increasing degree of visual control, as in biofeedback mechanisms [23]. Likewise, the performing of a dual-task can influence the motor performance [20] and [24]. Individuals with PD can perform normal movement patterns when they are focused on the movement performance, i.e. when they focus their attention on the implementation of the intended movements. In this situation, the non-injured premotor cortex is activated, without allocating the injured basal ganglia circuit, thereby facilitating the production of movements. When two tasks are performed simultaneously, there is a competition for limited resources, given that the cortical resources are used to perform motor tasks, resulting in interference of the dual-task and in performance deterioration of one or both tasks [9]. In the present study, clear distinctions were found between the single-task with eyes-open and the other conditions (single-task with eyes-closed and dual-task – while performing two different verbal fluency tasks). Also, the standing balance was found to be worse in more complex tasks (eyes-closed while performing the additional tasks). However, one should argue that the impact of dual-task is related to the complexity of the tasks [10] and [25]. Regarding the tasks selected for this study, the semantic and phonetic tasks activate different parts of the brain and represent a different level of complexity for different people. The phonetic fluency tasks are more associated with executive function, while the semantic fluency tasks are more closely related to the recovery of information [26] and [27]. The fact that the cognitive function of all participants (assessed with MMSE) was relatively preserved might explain why the standing balance in dual-task had values near the eyes-closed single-task condition.

Also, the impact of increasing the complexity of the tasks was relatively similar for the two groups. Although the changes in the CoP based parameters, especially in the maximum CoP displacement in the ML direction and in the mean CoP velocity, across tasks were greater for the individuals with PD, the values of these parameters did not significantly differ from the ones presented by the controls. Some studies [28] and [29] have found that individuals with PD have greater standing balance difficulties in dual-task conditions because they need to assign resources previously recruited in order to compensate the deficits in postural control. However, considering that the participants in this study were in early to middle stages of the disease, it is arguable that they did not have the need to recruit significantly more attentional strategies to maintain the postural stability than the controls. Moreover, the added complexity of the dual-task conditions selected for this study might not have been enough to affect these attentional strategies and therefore, the ability of the individuals with PD to maintain the standing balance [7]. Consequently, one can argue that if more cognitively demanding tasks were selected and/or if the PD participants were in later stages of the disease, the results could have been different. It would also be possible to claim that the results of the present study can be explained by the differences in cognitive status between groups or by different prioritization strategies, i.e. enunciate a reduced amount of words in verbal fluency tasks in order to maintain standing balance; however, no statistically significant differences were found between groups regarding the MMSE score and number of words enunciated in dual-task conditions [10] and [30].

This is the first study that compares individuals with PD to subjects without the disease regarding the changes in the standing balance resulting from performing an additional task. However, some limitations of the study performed can be pointed out. First, the size of the sample and the sampling method could have limited the results in regard to generalizability. Second, the cognitive tasks that were chosen might not have been complex enough to detect the differences between the individuals with PD and the controls. Likewise, the findings could have been different if other CoP based parameters were studied, for example, the length of the CoP path.

5. Conclusion

The present study showed that the standing balance of individuals with PD is worse than controls. This evidence should provide some guidance for further studies and for the planning of therapeutic interventions, with the aim to improve the functional performance of individuals with PD and delay the oncoming of further disabilities.

Future studies should focus on how different cognitive tasks affect the individual's standing balance, as well as to further investigate the relationship between the single-task condition “eyes closed” and the remaining single- and dual-task conditions. Researchers should also focus on understanding the changes in the CoP based values between single- and dual-task conditions across PD severity and age groups of individuals with PD.

Conflict of interest

None declared.

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