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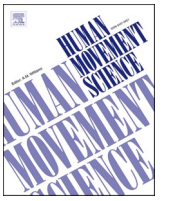

Effects on intermittent postural control in people with Parkinson's due to a dual task.

A. Marco-Ahulló [a], T. Mayordomo [a], A. Sales [b], M. Pellicer-Chenoll [c], I. Villarrasa-Sapiña [d,*], J.C. Melendez [b]

[a] Departamento de Neuropsicobiología, Metodología y Psicología Social, Universidad Católica de Valencia, Valencia, Spain
[b] Departamento de Psicología Evolutiva y de la Educación, Universidad de Valencia, Valencia, Spain
[c] Departamento de Educación Física y Deportiva, Universidad de Valencia, Valencia, Spain
[d] Facultad de educación, Universidad Internacional de la Rioja, Logroño, Spain

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ABSTRACT

Objectives: The aim of the present study was to determine the effects of performing a dual task on the sway density plot parameters in Parkinson's disease and control subjects.
Methods: A cross-sectional design was used to establish differences in the mean peak, mean time, and mean distance between a group with Parkinson's disease and a control group without Parkinson's disease. The subjects performed, in a unique measurement session, two trials under three different randomized conditions: i. eyes open, ii. eyes closed, and iii. Eyes open with foam base. One trial was performed as a single task (i.e., the subjects completed one of the balance test), while the other trial was performed as a dual task (i.e., the subjects performed a cognitive task at the same time that they maintained the static balance).
Results: There was a group x dual task x condition effect in mean peak ($F_{1.5,\ 51.1} = 5.21$; $p = 0.015$; $\eta^2_p = 0.13$) and mean time ($F_{1.4,\ 47.3} = 4.43$; $p = 0.03$; $\eta^2_p = 0.11$) variables. According dual-task cost analysis, there was a main effect of the condition ($F_{6,134} = 2.44$; $p = 0.05$; $\eta^2_p = 0.34$) on MD ($F_{2,68} = 6.90$; $p < 0.01$; $\eta 2p = 0.17$).
Conclusions: This result indicates differences in the dual task interference in the postural control mechanisms between the Parkinson's disease population and healthy pairs. For easy dual tasks, the Parkinson subjects used anticipatory control responses for longer periods of time, and for more difficult tasks, their control strategy did not change regarding single balance task.

1. Introduction

People with Parkinson's disease tend to experience frequent falls, which limit their functionality and quality of life (Allen, Schwarzel, & Canning, 2013; Dennison et al., 2007). This high frequency of falls has been associated with impaired balance function (Mak & Pang, 2009; Matinolli et al., 2009; Matinolli, Korpelainen, Sotaniemi, Myllylä, & Korpelainen, 2011; Robinson et al., 2005). There are four possible postural control mechanisms that can be affected in the development of this pathology (Schoneburg, Mancini, Horak, & Nutt, 2013): i. balance during quiet standing, ii. reactive postural adjustments to external perturbations, iii. Anticipatory postural adjustments, and iv. dynamic balance during movements like walking.

* Corresponding author at: Facultad de educación, Universidad Internacional de La Rioja, Logroño, (Spain).
E-mail address: israel.villarrasa@unir.net (I. Villarrasa-Sapiña).

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All of these systems have been studied in people with Parkinson's disease, and some associated perturbations have been observed (Schoneburg et al., 2013). Regarding the balance study during quiet standing (in which force plates were used), a larger center of pressure (CoP) sway path and increased sway area, root mean square, mean distance, mean frequency, sway ratio in the antero-posterior and medio-lateral directions have been described in people with Parkinson's disease compared to persons without Parkinson's disease (Błaszczyk & Orawiec, 2011; Błaszczyk, Orawiec, Duda-Kłodowska, & Opala, 2007; Mancini et al., 2012). Furthermore, this population has demonstrated a deficit in the reweighting of sensory information for postural control when conducting activities while the sensory inputs were intentionally disturbed (Brown et al., 2006; Schoneburg et al., 2013). One of the most important related findings is the high dependence on the visual system to achieve proper balance maintenance (Bronstein, Hood, Gresty, & Panagi, 1990).

Not only balance function is a factor associated with falling in Parkinson's disease. Attention has been reported as another important predictor of falling. In this sense, some authors have reported that a dual task (i.e., cognitive or motor secondary activity) deteriorates the balance in people with Parkinson's disease (Bekkers et al., 2018; de Andrade et al., 2014; Marchese, Bove, & Abbruzzese, 2003; Morris, Iansek, Smithson, & Huxham, 2000). Recently it has been published a study in which executive function has been established as a significant predictor of single-leg stance performance test ($r^2 = 0.09$) (Paul, Sherrington, Fung, & Canning, 2013). Nevertheless, Holmes et al., found that dual task interference was greater in healthy than in Parkinson's disease people (Holmes, Jenkins, Johnson, Adams, & Spaulding, 2010). There are variables like task difficulty, falling fear, fall history, leg strength… that affect dual task interference and could explain these contradictory results (Bloem, Grimbergen, van Dijk, & Munneke, 2006; Marchese et al., 2003; Morris et al., 2000; Paul et al., 2014; Pellecchia, 2003; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997).

To date, parameters used in the published studies regarding dual task interference in Parkinson's disease considered the CoP as a signal of movement (and not as a signal of the motor control) related to ankle torque (Baratto, Morasso, Re, & Spada, 2002). These variables report information about task performance but not about control strategies. For this reason, the sway density plot parameters in the present study were extracted from the CoP signal. The sway density plot analysis was proposed by Baratto et al. (Baratto et al., 2002), based on the inverted pendulum theory, and has been applied in several studies reporting balance control analyses (Baratto et al., 2002; García-Massó, Estevan, Izquierdo-Herrera, Villarrasa-Sapiña, & Gonzalez, 2019; Jacono, Casadio, Morasso, & Sanguineti, 2004; Mello, Oliveira, & Nadal, 2009; Simoneau, Mercier, Blouin, Allard, & Teasdale, 2006; Villarrasa-Sapiña et al., 2016; Villarrasa-Sapiña et al., 2018). However, this analysis has not been applied to the investigation of the dual task interference effect in Parkinson's disease.

This analysis method considers an intermittent postural control model in which two control actions are alternated. The first is the intrinsic feedback, which originates from the mechanical properties of the ankle muscles. This is a short-term mechanism that reduces the natural falling movement of an inverted pendulum. The second is integrated by the anticipatory muscular activation (active control) that can be modeled as a feedback or feedforward control system. Latter is a long-term action which function is to restore the reference position of the center body mass.

Normally, the sway density plot analysis is performed based on the displacement pattern of the CoP (Baratto et al., 2002). The CoP remains relatively stable (with only small movements) over a period of time. These small movements are a consequence of the natural fall of the center of mass, which is restrained by a passive control mechanism based on ankle stiffness and segmental reflexes. Between two consecutive periods of stability, the central nervous system sends a descending motor command to move the CoP position beyond the anticipated center of mass position to return to the reference position. Thus, the analysis uses as a framework a model of intermittent postural control that alternates between two control strategies (i.e., active and passive).

Considering the aforementioned studies on the influence of dual tasks in Parkinson's disease and as postural control is affected by dual tasks in other populations that have more altered balance than healthy adults (children, people with obesity, or the base of support used) (Bustillo-Casero, Villarrasa-Sapiña, & García-Massó, 2017; Mignardot, Olivier, Promayon, & Nougier, 2010; Villarrasa-Sapiña, Estevan, Gonzalez, Marco-Ahulló, & García-Massó, 2020), the hypothesis of this study is that the postural control of people with Parkinson's disease is more altered by a dual task than people without Parkinson's disease. The aim of the present study was to determine the effects of performing a dual task on the sway density plot parameters in Parkinson's disease and subjects without Parkinson's disease. Moreover, the effects of the dual task in these groups were tested with visual constraints and somato-sensory modified conditions.

2. Material and methods

2.1. Study design

A cross-sectional, retrospective, inter-subjects design was used to determine differences in the postural control variables between a group of persons with Parkinson's disease compared to a control group without Parkinson. The subjects performed two trials under three different randomized conditions during a unique measurement session: i. eyes open, ii. eyes closed, and iii. Eyes open with foam base. One trial was performed as a single task (i.e., the subjects completed one of the balance tests), while the other trial was performed as a dual task (i.e., the subjects performed a cognitive task at the same time they maintained the static balance). Once the postural control data were acquired, the signals were digitally processed in order to extract sway density plot variables.

2.2. Participants

Eighteen patients diagnosed with Parkinson's disease voluntarily participated in the study. The subjects were recruited from the

Parkinson Association in our region. Diagnosis for the patients was based on the United Kingdom Parkinson's disease Society Brain Bank's Diagnostic Criteria (Hughes, Daniel, Kilford, & Lees, 1992). These criteria require the presence of at least two of the following three symptoms: i. resting tremor, ii. rigidity, and iii. Bradykinesia. All the participants in the Parkinson group had a Hoehn and Yahr (Hoehn & Yahr, 1967) rating of Stage III and were receiving medication, which included dopaminergic treatment with carbidopa-levodopa and/or MAO inhibitors (selegiline and rasagiline) and/or dopaminergic agonists (rotigotine, pramipexole, ropinirole).

The exclusion criteria for the Parkinson group included the following: i. the patient had a significant cognitive impairment (a score below 24 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975)), ii. the patient suffered from other neurological conditions, or iii. The patient suffered from any pathological condition that would interfere with the safety or validity of the assessment.

Eighteen healthy pairs participated in the study as the control group. Subject characteristics of both groups are shown in Table 1. The subjects in the control group did not suffer from Parkinson's disease, other neurological condition, or other pathological conditions that affected postural control.

The Ethical Committee of our institution approved the project. Written informed consent forms were obtained from participants prior to participation in the study.

2.3. Posturographic measurements

In order to measure postural stability, a force plate was used (Dinascan/IBV, Biomechanics Institute of Valencia, Valencia, Spain). The platform consisted of a 600 mm × 370 mm plate, with a 100 mm height and four force transducers. The platform was placed on a stable surface to avoid distortion signal noise.

Single and dual tasks were performed. In single tasks, the subjects stood still, while barefoot, in a relaxed manner with their arms by their sides. The same foot placement was adopted in all trials (i.e., heels separated approximate 3 cm and toes pointing outward at an angle of 20° from the sagittal midline), according to the specifications of the manufacturer. A point of reference (5 cm in diameter) was placed opposite the subject at eye level at a distance of 2 m. All subjects were informed of the importance of maintaining this posture and were asked to attempt to minimize any abnormal movement.

In the dual task, the subjects performed the same balance task while performing a cognitive task. The cognitive task consisted of subtracting three from one hundred until the end of the task. If the subjects arrived at zero, they repeated task until the allotted time had ended.

For both tasks, one 90 s attempt was made under each of the following three conditions: eyes open, eyes closed and eyes open with foam. The order of the tasks and conditions were randomized to avoid undesirable effects. During each postural trial, signals were recorded at a frequency of 40 Hz using an amplified analogue-to-digital converter. Data representing the forces exerted on the platform along three axes (x, y, z) were saved on a hard disk for subsequent analysis.

2.4. Digital signal processing

The CoP displacement data, both in the mediolateral and the anteroposterior directions, were obtained using the analysis software NedSVE/IBV (Biomechanics Institute of Valencia, Valencia, Spain).

These data were analyzed using Matlab R2013a (Mathworks Inc., Natick, USA). The CoP signals were pre-processed to attenuate the noise using a low pass Equiripple FIR filter (cut off frequency 6 Hz, 16 order). The signals were then edited in order to exclude the first and last 10 s of each trial. Using the selected period of time, the sway density plot was computed. The number of consecutive samples during which the CoP remained inside a 3 mm radius was computed. This is done for each data point. A signal is then obtained in which the x-axis represents the time and the y-axis the number of points. The sample count was multiplied by the sample period in order to obtain a time versus time curve, representing the evolution of the stability of the CoP over time. The next step is to perform peak detection. The peaks represent the amount of time in which the CoP is relatively stable, whereas the valleys are instants in which the CoP rapidly shifts the CoM forward as a consequence of anticipatory commands from the central nervous system. Once the sway density plot was computed, it was filtered in both direct and reverse directions using a fourth order Butterworth filter with a 2.5 Hz cut-off frequency (Fig. 1) (Baratto et al., 2002; Jacono et al., 2004). Both control actions (i.e., intrinsic feedback and anticipatory commands) can be quantified by three parameters: the mean peak (MP), which represents the mean time that the CoP can be stabilized

Table 1
Subject's characteristics.

	Parkinson group ($n = 18$)	Control group ($n = 18$)
Sex		
Male	10	6
Female	8	12
Weight (kg)	71.42 (4.46)	77.15 (3.88)
Height (m)	1.61 (0.02)	1.64 (0.02)
BMI ($kg{\cdot}m^{-2}$)	27.35 (1.23)	28.46 (1.26)
Age (years)	70.33 (1.85)	66.64 (1.34)
PD duration (months)	81.3 (23.88)	

Data are expressed as mean (SEM). BMI = body mass index, and PD = Parkinson Disease.

using the intrinsic feedback alone; the mean time (MT), which represents the time between successive phases of anticipatory control; and the mean distance (MD), which represents the amplitude of the shifts of the posturographic activity and therefore the magnitude of the anticipatory response.

2.5. Statistical analysis

Statistical analysis was performed with SPSS 24 (IBM, Armonk, USA). Descriptive methods were used to compute the mean and the standard error of the mean (SEM). Normality (Shapiro-Wilk test), and homoscedasticity (Levene's test) assumptions were checked and, although some variables did not meet the assumptions, since the sample is sufficiently large (more than 30 subjects) and both groups have the same number of subjects, we can be more confident that the sampling distribution is normally distributed (Field, 2009). On the one hand, a mixed model MANOVA [group (2) x condition (3) x dual task (2)] was applied to check the effects of the group, condition, and dual task on the dependent variables. The follow-up was performed by means of univariate contrast. When significant univariate contrasts were found, pair-wise comparisons were requested with the Bonferroni correction.

On the other hand, the dual-talk cost was calculated (Eq. (1)) with sway density plot variables (i.e., MP, MD and MT) to know the dual task cost on postural control variables. Another mixed model MANOVA [group (2) x condition (3)] was applied to check the effects of the group and condition on the dependent variables. Likewise, significant univariate contrasts were found, pair-wise comparisons were requested with the Bonferroni correction. A p-value of 0.05 was accepted as the level of significance for all statistical analyses.

$$\frac{(Dual\ task - Single\ task)}{Single\ task} \tag{1}$$

3. Results

On the first analysis, the multivariate contrast showed that there was a main effect of the group ($F_{3,32} = 7.33$; $p = 0.001$; $\eta^2_p = 0.41$), dual task ($F_{3,32} = 9.59$; $p < 0.001$; $\eta^2_p = 0.47$) and condition ($F_{6,29} = 22.98$; $p < 0.001$; $\eta^2_p = 0.83$) on the dependent variables. For the interaction effects, there was a group x dual task x condition effect ($F_{6,29} = 2.6$; $p = 0.039$; $\eta^2_p = 0.35$).

The univariate analysis showed a main effect of group on MD ($F_{1,34} = 10.38$; $p = 0.003$; $\eta^2_p = 0.23$), MP ($F_{1,34} = 8.57$; $p = 0.006$; $\eta^2_p = 0.2$) and MT ($F_{1,34} = 16.42$; $p < 0.001$; $\eta^2_p = 0.33$). Furthermore, there was a main effect of the dual task on MD ($F_{1,34} = 9.37$; $p = 0.004$; $\eta^2_p = 0.22$) and MP ($F_{1,34} = 29$; $p < 0.001$; $\eta^2_p = 0.46$). Finally, there was a main effect of the condition on MD ($F_{2,\ 68} = 30.63$; $p < 0.001$; $\eta^2_p = 0.47$), MP ($F_{1.4,\ 48.5} = 57.5$; $p < 0.001$; $\eta^2_p = 0.63$) and MT ($F_{1.4,\ 46.4} = 4.54$; $p = 0.028$; $\eta^2_p = 0.12$). Regarding interactions, there was a group x dual task x condition effect on MP ($F_{1.5,\ 51.1} = 5.21$; $p = 0.015$; $\eta^2_p = 0.13$) and MT ($F_{1.4,\ 47.3} = 4.43$; $p = 0.03$; $\eta^2_p = 0.11$).

Pairwise comparisons showed that MD and MT were higher in the Parkinson group than in the control group ($p < 0.05$). Nevertheless, MP was lower in the Parkinson group than in the control group ($p < 0.05$, Fig. 2). Furthermore, MD was higher in the dual task, while MP was higher in the single task ($p < 0.05$). Moreover, MD was lower in the eyes open condition than eyes closed and eyes open with foam ($p < 0.05$). The MD during eyes closed was lower than during eyes open with foam ($p < 0.05$). Regarding MP, this variable was higher in eyes open than in eyes closed and eyes open with foam ($p < 0.05$). Furthermore, MP was higher in eyes closed than in eyes open with foam ($p < 0.05$). In the eyes closed condition, the MT was lower than in the eyes open and eyes open with foam conditions ($p < 0.05$).

Moreover, during the eyes open condition the MP was higher in the single task than in the dual task in the control group ($p < 0.05$) while the MT was higher in the dual task than in single task for the Parkinson group ($p < 0.05$, Table 2).

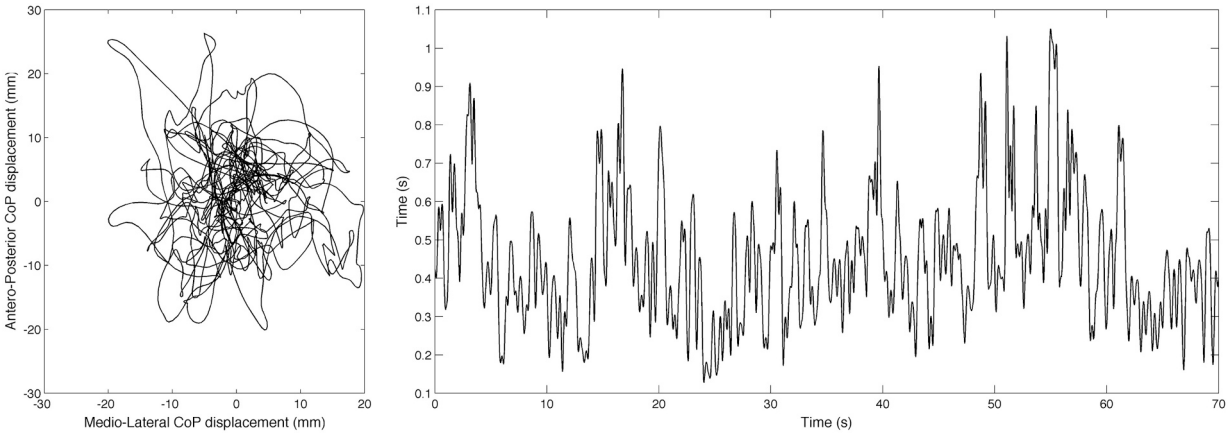

Fig. 1. Example of signal processing of a Parkinson disease subject during single task eyes open with foam base condition. In the left layer the statokinesigram is represented. In the right layer the sway density plot is shown.

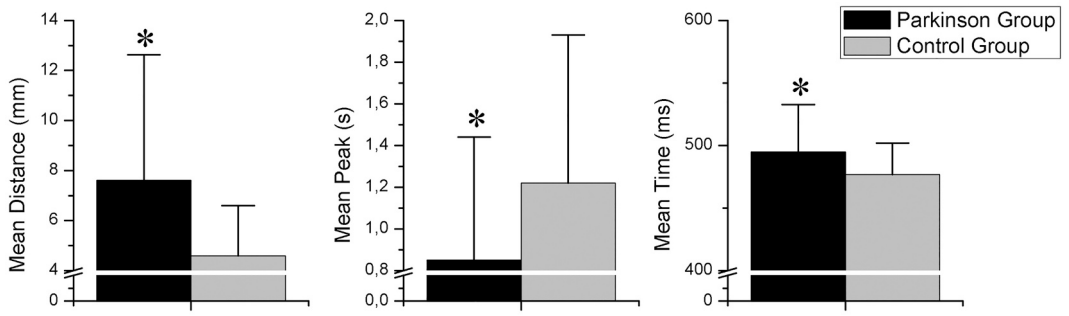

Fig. 2. Differences between Parkinson's and Control Group in sway density plot variables. *Indicate significant differences ($p < 0.05$) related to Control Group.

In the control group, the MP was higher in the eyes open than in eyes closed and eyes open with foam conditions ($p < 0.05$). Moreover, in the eyes closed condition, the MP was higher than in the eyes open with foam condition ($p < 0.05$). These results were found both in the single and dual tasks. In the same group, the MT was higher in the eyes open than in the eyes closed condition ($p < 0.05$) only during the single task. Regarding the Parkinson group, the MP was higher in eyes open than in eyes open with foam both in the single and dual tasks ($p < 0.05$). The MT was higher in the eyes open with foam than in the eyes open and eyes closed conditions in the single task ($p < 0.05$). During the dual task, the MT was higher in the eyes open with foam than during the eyes closed condition ($p < 0.05$). Table 2 represents the differences between groups in the different conditions for dual and single tasks.

On the second analysis, the multivariate contrast showed that there was a main effect of the condition ($F_{6,29} = 2.44$; $p = 0.05$; $\eta^2_p = 0.34$) on the dependent variables. The univariate analysis showed a main effect of condition on MD ($F_{2,68} = 6.90$; $p < 0.01$; $\eta^2_p = 0.17$). Pairwise comparisons showed that MD was higher in the eyes open condition than eyes closed ($p < 0.05$, Fig. 3).

4. Discussion

There are some differences in the postural control mechanisms between people with and without Parkinson's disease. It has been observed that the MD and MT values were higher in the Parkinson group than the control group, while the MP value was larger in the control group than the Parkinson group. This could indicate that people with Parkinson's disease have different postural control mechanisms. It seems as though people with Parkinson's disease maintain their postural equilibrium through anticipatory commands of higher amplitude (i.e., higher MD), but this mechanism acts with lower periodicity (i.e., higher MT) than in control group. These results are similar to those of previous studies that compared persons with and without Parkinson's disease using sway density plot analysis. Mitchell et al. (Mitchell, Collins, De Luca, Burrows, & Lipsitz, 1995) found that persons with Parkinson's disease showed a higher long-term closed-loop control. Similarly, Maurer et al. (Maurer, Mergner, & Peterka, 2004) found higher values for closed-loop and open-loop control in people with Parkinson's disease than in healthy controls. In the aforementioned studies, the authors used a stabilogram diffusion analysis to obtain the results. Therefore, in these studies it was hypothesized that human balance could be modeled as Brownian motion. This approach ignores the biomechanics of the inverted pendulum while sway density plot analysis is based in inverted pendulum biomechanics (Baratto et al., 2002).

Regarding the dual task effect, we found that MP was higher in the single task than in the dual task. Nevertheless, the anticipatory control was more involved in the dual task. This could be due to the fact that when cortical areas responsible for the cognitive tasks are stimulated when performing the dual task, the efferences increase in order to control the equilibrium by means of anticipatory responses, which in turn can lead to a reduction of the time in which balance is maintained entirely by ankle joint properties and reflexes.

Table 2
Differences between single task and dual task and between groups.

		Parkinson group ($n = 18$)		Control group ($n = 18$)	
		Single task	Dual task	Single task	Dual task
Mean Peaks (s)	*EO*	1.24 (0.15)†	0.98 (0.17)†	2.25 (0.21)*	1.45 (0.13)
	EC	0.9 (0.14)	0.74 (011)†	1.08 (0.07)	1.09 (0.1)
	EOF	0.68 (0.12)	0.55 (0.05)	0.76 (0.03)	0.67 (0.03)
Mean Distance (mm)	*EO*	4.5 (0.61)	7.31 (1.3)	2.46 (0.17)	3.68 (0.3)
	EC	7.15 (1.12)	8.11 (1.43)	4.28 (0.32)	4.08 (0.26)
	EOF	8.59 (0.76)	9.99 (1.34)	6.09 (0.39)	6.96 (0.4)
Mean Time (ms)	*EO*	481.9 (6.1)*	511.1 (14.24)	492.0 (7.2)	480.6 (6.79)
	EC	489.7 (6.5)†	481.4 (8.21)	463.1 (3.93)	469.7 (5.75)
	EOF	503.2 (5.07)†	502.9 (9.14)	473.8 (4.28)	482.1 (5.25)

Data are expressed as mean (SEM). OE = eyes open; OC = eyes closed; EOF = eyes open with foam base.
* Indicates significant differences ($p < 0.05$) related to dual task.
† Indicates significant differences ($p < 0.05$) related to Control Group.

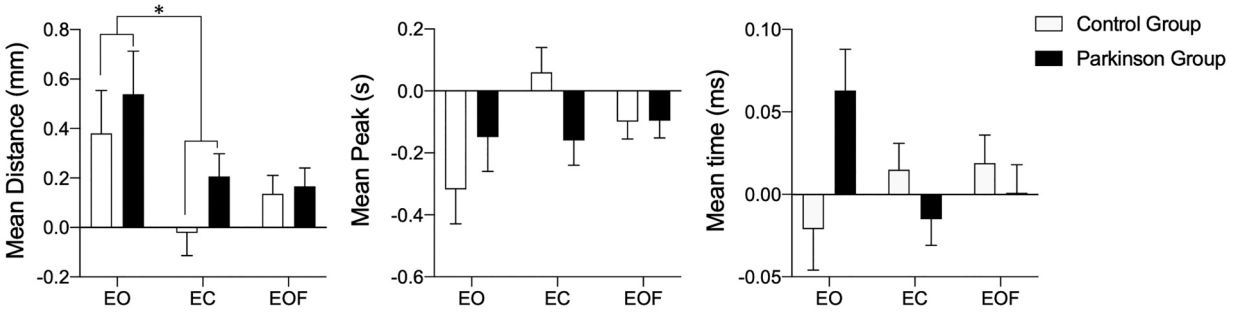

Fig. 3. Differences between the effect of postural tasks on dual task cost of postural control. The bars represent the mean and the error bars the standard error of mean. *Indicates indicates significant differences between conditions ($p < 0.05$).

The executive function (involved in the cognitive task of the present study) has been associated with postural control (Muir-Hunter et al., 2014). Therefore, it is possible that the higher requirements of this function (due to the dual task) lead to a higher activation of the central nervous system areas, which may lead to wider and more frequent anticipatory responses.

Nevertheless, there were differences in the postural control in the dual task interference between the Parkinson group and control group regarding the postural condition. Regarding control group in the eyes open condition, the interference of dual task reduces MP variable. In the same condition, the Parkinson group showed an increase in the MT as a consequence of the dual task. These results revealed an important alteration in the mechanism involved in the balance control in Parkinson group. In both cases, the results indicate that performing a dual task increases the use of the intermittent anticipatory control. Nevertheless, the method employed to achieve this is different between people with and without Parkinson's disease. People without Parkinson's disease compensate for the interference due to the cognitive task by increasing the frequency action of the anticipatory control mechanism. However, people with Parkinson's disease seem to employ for a longer period of time the anticipatory control response. It is possible that this population pays more attention to the postural control than to the cognitive task while conducting a dual task. This could lead to an increase in the time in which anticipatory neuronal commands are sent in order to control of the equilibrium. In contrast, people without Parkinson's disease divide their attention between tasks, which is rapidly swapped between tasks. However, when exigent balance tasks are required (i.e., eyes closed and eyes open with foam), neither of them change their balance control mechanisms implication while performing the dual task regarding single task. This can lead to a loss in the sway performance (i.e., greater sway) and an effective execution of the cognitive task, as has been reported in previous studies (Marchese et al., 2003; Morris et al., 2000; Shumway-Cook et al., 1997).

Finally, differences in MP among all the conditions in control group during the single task, as well as in dual task, were obtained. Nevertheless, only differences in the Parkinson group between eyes open and eyes open with foam were obtained both in single and dual tasks. This indicates that the control system was not adapted in Parkinson's disease subjects when the visual input was constrained. This lack of reweighting in the control mechanism could be responsible for the poorer sway control in persons with Parkinson's disease during eyes closed conditions, as previously reported (Bronstein et al., 1990; Brown et al., 2006).

According to the results obtained in this study, it is observed that the application of a dual task in conditions other than eyes open (i.e., eyes closed or eyes open with unstable surface) in people with Parkinson's disease, produces a performance in postural control with fewer differences between people with Parkinson's disease and their peers in the control group. Therefore, to improve in this rehabilitation field, it could be recommended to work on postural control by dual tasks (i.e., motor control task and easy cognitive task) in different conditions, such as those studied. However, this is a suggestion and there is not yet sufficient scientific evidence. Therefore, a future line of research should study whether this type of intervention is effective in maintaining or preventing a significant reduction in the deterioration of postural control in people with Parkinson's disease. In this way, the prevention of the risk of falls could also be promoted.

5. Conclusion

In conclusion, the Parkinson's disease group and control pairs showed differences in their balance control. The people with Parkinson's disease showed wider and more frequent anticipatory commands than the control subjects. Moreover, the control reweight during a dual task was dependent of the condition difficulty and group. When easy dual task was performed, the individuals with Parkinson's disease use the anticipatory control for longer periods of time regarding single task; the control strategy did not change in more difficult conditions. Persons without Parkinson's disease during easy dual tasks use the anticipatory control more frequently than in single task, but their control strategies seem to don't change for complex dual tasks.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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