

Parkinson's Disease and Cognitive-Motor Dual-Task: Is Motor Prioritization Possible in the Early Stages of the Disease?

Ângela Fernandes, Andreia S. P. Sousa, Nuno Rocha & João Manuel R. S. Tavares

To cite this article: Ângela Fernandes, Andreia S. P. Sousa, Nuno Rocha & João Manuel R. S. Tavares (2016) Parkinson's Disease and Cognitive-Motor Dual-Task: Is Motor Prioritization Possible in the Early Stages of the Disease?, *Journal of Motor Behavior*, 48:4, 377-383, DOI: [10.1080/00222895.2015.1105194](https://doi.org/10.1080/00222895.2015.1105194)

To link to this article: <https://doi.org/10.1080/00222895.2015.1105194>



Published online: 09 May 2016.



Submit your article to this journal [↗](#)



Article views: 309



View related articles [↗](#)



View Crossmark data [↗](#)



Citing articles: 2 View citing articles [↗](#)

RESEARCH ARTICLE

Parkinson's Disease and Cognitive-Motor Dual-Task: Is Motor Prioritization Possible in the Early Stages of the Disease?

Ângela Fernandes^{1,2}, Andreia S. P. Sousa³, Nuno Rocha¹, João Manuel R. S. Tavares⁴

¹Escola Superior da Tecnologia de Saúde do Instituto Politécnico do Porto, Área Científica de Terapia Ocupacional, Centro de Estudo do Movimento e da Atividade Humana, Portugal. ²Faculdade de Engenharia, Universidade do Porto, Portugal. ³Escola Superior da Tecnologia de Saúde do Instituto Politécnico do Porto, Área Científica de Fisioterapia, Centro de Estudo do Movimento e da Atividade Humana, Portugal. ⁴Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Portugal.

ABSTRACT. The authors aimed to compare the postural phase of gait initiation under single-task (gait initiation) and dual-task (gait initiation plus Stroop test) conditions in healthy subjects and in subjects with Parkinson's disease (PD) in the early stages (Hoehn and Yahr scale < 3). The postural phase of gait initiation was assessed through the centre of pressure in single and dual task in 10 healthy subjects and 9 with PD. The analysis indicated that in the early stages of PD, an additional cognitive task did not affect the displacement of the gait initiation. No significant effects occurred between the groups and within-subjects ($p > .05$). Also, no interaction was found between the groups and the conditions (single- and dual-task). Differences were found in the duration of the mediolateral postural phase ($p = .003$), which was higher in PD subjects than in healthy subjects. The findings suggest that subjects in the early stages of PD prioritize gait initiation, as their motor performance was similar to that of healthy subjects.

Keywords: dual task, postural phase, prioritization, Stroop test, gait initiation

A dual-task condition involves the execution of two tasks simultaneously. One is the main task, and the other is the secondary task (Kelly, Eusterbrock, & Shumway-Cook, 2012b; Nocera, Roemmich, Elrod, Altmann, & Hass, 2013; Sethi & Raja, 2012). The performance of two tasks simultaneously leads to a competition for limited resources that results in the deterioration of the performance of one or both tasks (Kelly et al., 2012a; Wu & Hallett, 2009).

Biomechanical studies of postural stability have demonstrated that in a dual-task condition, subjects with Parkinson's disease (PD) exhibit impaired postural control. In addition, some authors have suggested that the dual-task condition restricts their anticipatory postural adjustments (APAs) to focus on the cognitive task without losing balance (Nocera et al., 2013; Yogeve-Seligmann et al., 2010).

Postural phase of gait initiation (GI) is associated to the interval between the first vertical impulse, due to the APAs, until the maximum center of pressure (CoP) displacement backward and toward the first swing limb. It is characterized by a backward displacement of CoP that results from the APAs causing a forward displacement of the centre of gravity (Caderby et al., 2013; Yiou, Caderby, & Hussein, 2012). Subjects with PD often have difficulties in generating APAs, particularly

in forward propulsion and lateral weight shift when initiating gait (Hall, Brauer, Horak, & Hodges, 2013). Studies involving subjects with PD have shown that the duration of APAs is extended, the backward and lateral displacements of the CoP are reduced and the length and velocity of the first step are shortened (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997; Crenna et al., 2006; Gantchev, Viallet, & Aurenty, 1996; Hall et al., 2013; Halliday, Winter, Frank, Patla, & Prince, 1998; Rogers et al., 2011), increasing the risk of falls (Kelly et al., 2012a; Schmit et al., 2005).

Difficulties in performing two tasks simultaneously may be associated with impairment of executive function and attention deficits, which are characteristics of PD (Hausdorff et al., 2006). When subjects with PD focus on the motor performance, they can perform normal patterns of movement by activating the uninjured premotor cortex and not using the injured basal ganglia circuit, thereby ensuring the performance of movements. However, in dual-task condition, the use of cortical resources to carry out motor tasks may compromise or influence the performance of one or both tasks (Holmes, Jenkins, Johnson, Adams, & Spaulding, 2010a; Kelly et al., 2012a; Wu & Hallett, 2009).

Furthermore, several studies have revealed higher instability in upright standing in individuals over 65 years old with and without any pathology, which becomes more notorious in the individuals after stage 3 of PD (Tsutiya et al., 2011). However, there is a lack of information about the early stages of PD as well as the influence of the dual-task in GI. Therefore, the aim of this study was to compare the postural phase on GI in single- and dual-task conditions in healthy subjects and in subjects in the early stages of PD (Hoehn and Yahr scale < 3). Therefore, the anteroposterior and mediolateral CoP displacements, the anteroposterior and mediolateral velocities of the CoP displacements, and the anteroposterior and mediolateral durations of the postural phase were assessed.

Correspondence address: João Manuel R. S. Tavares, Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal. E-mail: tavares@fe.up.pt

METHODS

Subjects

A cross-sectional study was implemented using a non-probabilistic convenience sample (Doherty, 1994) of nine subjects with PD and 10 healthy subjects, between 52 and 80 years old. The size of the sample used is in line with other studies of this kind, such as the studies of Nocera et al. (2013), with 13 PD individuals; Halliday et al. (1998), with 10 PD individuals; Holmes et al. (2010a), with 12 PD individuals; Rogers et al. (2011), with 8 PD individuals; Schmit et al. (2005), with six PD subjects; Hiraoka, Matsuo, Iwata, Onishi, and Abe (2006), with nine PD subjects; and Hiraoka, Matsuo, and Abe (2005), with 11 PD subjects. The subjects diagnosed with PD were patients from the Parkinson's Association in Porto, Portugal, while the healthy controls were community-dwelling volunteers mainly from Porto, Portugal.

Subjects were excluded if they presented one of the following factors: incapable of walking independently (based on the Timed Up and Go test [TUG] score until 10 s; Podsiadlo & Richardson, 1991), unable to speak, and severe cognitive impairment (screened with the Montreal Cognitive Assessment [MoCA]; Hoops et al., 2009). The option for the MoCA test was based on the study by Chou et al. (2010), who analyzed five statistical tests and recommended it as a standard cognitive screening instrument to be used in clinical trials with PD patients. The reasons for this recommendation are that it can be performed quickly and has the potential to identify subtle executive dysfunctions, while covering the major cognitive domains. Severely disabled PD patients (>3 Hoehn and Yahr Scale; Hoehn & Yahr, 1967), patients diagnosed with any other neuromuscular disease, or those who had undergone deep brain stimulation through subthalamic surgery or were under cholinergic medication were also excluded. Healthy subjects that have been diagnosed as adults with any neuromuscular disorder or that cannot be considered sedentary, according to the Centers for Disease Control for the American College of Sports Medicine, were also excluded (Pate et al., 1995).

A trained researcher conducted the data collection based on a structured protocol. The study was approved by the Ethical Review Board of the Escola Superior de Tecnologia da Saúde—Instituto Politécnico do Porto, in Portugal. Written informed consent, according to the Helsinki Declaration, was obtained from all subjects.

Instruments

The data collected from all subjects included sociodemographic characteristics (age, gender, height, weight, and level of education), years of disease, cognitive performance (assessed by the MoCA test), functional mobility (evaluated using the TUG test), number of colors correctly named and

errors according to the Stroop test, and values in terms of the Hoehn and Yahr scale (Hoehn & Yahr, 1967).

The Hoehn and Yahr scale (Hoehn & Yahr, 1967) is commonly used to assess the severity of overall dysfunction in PD subjects. It is a 7-point scale, in which each point represents 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.

The values of the vertical, anteroposterior and mediolateral components of the ground reaction forces (GRF) were obtained from a force platform, model FP4060-8 from Bertec Corporation (), according to a sampling rate of 1000 Hz (Hanke & Rogers, 1992). The platform was connected to a Bertec AM 6300 amplifier (Columbus, OH) and in turn, this was connected to an analog-digital converter from Biopac Systems, Inc. (Santa Barbara, CA), and to an analog board of Qualisys Track Manager (Göteborg, Sweden) that can be used for stabilometric analyses. The force platform signals were digitized and stored for subsequent analysis in Acqknowledge (Biopac Systems, Inc.).

Procedures

After an explanation of all the procedures involved, all individuals performed the tasks with shorts and standard shoes (sneakers with laces) that were provided for the study to be similar for all individuals. In the single-task condition, the subjects were asked to remaining in the standing position for 30 s, looking at a point at eye level 2 m away. After this interval, the subjects were instructed to walk three steps at a self-selected speed. In the dual-task condition, the previous procedures were repeated; however, the subjects were required to perform the Stroop test simultaneously, which consisted of naming the color used to print the name of a different color (Romann, Dornelles, Maineri, Rieder, & Olchik, 2012). The order of each condition (single- and dual-task) changed randomly, from individual to individual, to avoid a learning effect. There was a 1-min rest between each trial, and all necessary repetitions were performed to obtain three valid trials to reduce the within-individual variability and increase the statistical power (Mullineaux, Bartlett, & Bennett, 2001). All the experimental data were acquired by the same trained researcher to ensure reproducibility.

The CoP signal was low-pass filtered with a fourth-order Butterworth filter (zero-phase lag) with a cutoff frequency of 8 Hz (Winter, 2009). The postural phase was defined as the interval between the starting of the CoP displacement (T0) until the maximum CoP displacement backward and toward the first swing limb. The T0 was identified as the instant when the CoP signal deviated from the baseline (obtained in standing position) plus three standard deviations for a minimum interval of 50 ms (Shiratori & Latash, 2001). The end of the postural phase was defined as the instant associated to the first deflection of the CoP displacement (Tsukahara, Kawanishi, Hasegawa, & Sankai, 2010).

The values of the anteroposterior CoP displacement (CoP_{AP}) and mediolateral CoP displacement (CoP_{ML}), anteroposterior duration of the postural phase ($Duration_{AP}$) and mediolateral duration of the postural phase ($Duration_{ML}$), and anteroposterior velocity of the CoP displacement (Vel_{AP}) and mediolateral velocity of the CoP displacement (Vel_{ML}) were used for analysis.

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. All the variables analyzed presented a normal distribution, so multivariate analysis of variance (MANOVA) for repeated measures was used for multivariate analysis between healthy subjects and PD subjects in the single- and dual-task conditions, and all variables were assessed simultaneously. For additional evaluations, the independent samples *t* test was used to obtain results regarding the differences for the various conditions between groups, while paired samples *t* test was used to analyze the differences between the single- and dual-task conditions in each group. Two-tailed tests were used in all analyses done and $p < .05$ was adopted for statistical significance. All statistical analyses were run using SPSS version 22.0 (SPSS Inc., Chicago, IL).

RESULTS

The PD sample had nine subjects (66.7% male), with a mean age of 66 years old ($SD = 8.2$ years), a mean education of 7.7 years ($SD = 5.1$ years), and a mean years of disease of 10.22 ($SD = 5.38$ years). Most of these subjects were classified as stage 1 and 1.5 of the Hoehn and Yahr scale, with a mean of 8.39 s ($SD = 0.86$ s) in the TUG test. The healthy sample had 10 subjects (50% male), with a mean age of 63.7 years ($SD = 7.6$ years) and a mean education of 8.2 years ($SD = 4.5$ years). When both groups were compared, statistically significant differences were only found in the number of the colors correctly named on the Stroop test. PD subjects scored less than the healthy subjects, Table 1.

The analysis of repeated measures MANOVA, indicated that there were no significant multivariate effects between the healthy and PD subjects studied, $F(6, 11) = 2.030$, $p > .05$, $\eta_p^2 = .525$, nor within subjects independently of their group, $F(6, 11) = 0.973$, $p > .05$, $\eta_p^2 = .347$. Also, no relation was found between the groups and conditions, $F(6, 11) = 0.982$, $p > .05$, $\eta_p^2 = .349$. Univariate analysis between the groups indicated that the $Duration_{ML}$ was significantly higher for the PD subjects than for the healthy subjects, $F(1, 16) = 12.494$, $p = .003$, $\eta_p^2 = .44$. A significant relation was found between the conditions and groups for the $Duration_{ML}$, $F(1, 16) = 4.717$, $p = .045$, $\eta_p^2 = .228$.

Although the CoP_{AP} and Vel_{ML} did not present significant differences between the groups, large between-group effects were found ($\eta_p^2 = .07$ and $\eta_p^2 = .08$, respectively). Considering the within-group univariate analysis, no differences were detected between the single- and dual-task conditions. Nevertheless, within the healthy group, large effect sizes (*d*) were found for the $Duration_{ML}$, $Duration_{AP}$ and Vel_{ML} , and small for the CoP_{AP} , CoP_{ML} , and Vel_{AP} . Within the Parkinson's group, the effect sizes (*d*) were large for the $Duration_{ML}$, medium for the $Duration_{AP}$ and small for the CoP_{AP} and Vel_{AP} , Table 2.

The significant relations found were explored further. In the dual-task condition, the PD subjects had a significantly higher $Duration_{ML}$ than the healthy subjects, $t(17) = -3.536$, $p = .003$. When single- and dual-task conditions were compared, no significant difference was found between the conditions in subjects with PD. However, in healthy subjects, the $Duration_{ML}$ was significantly lower in the dual-task condition than in the single-task condition, $t(9) = -2.496$, $p = .034$ (Figure 1).

DISCUSSION

The aim of this study was to compare the postural phase of GI in single- and dual-task conditions in healthy subjects and in PD subjects in the early stages of the disease (Hoehn and Yahr scale < 3). In contrast to what was expected, no significant differences were observed between subjects with PD and healthy subjects regarding the CoP_{AP} , CoP_{ML} , $Vel_{CoP_{AP}}$, and $Vel_{CoP_{ML}}$. However, the mean CoP_{AP} and CoP_{ML} displacements were lower in the subjects with PD.

Previous studies of APAs associated with GI have shown that the backward CoP displacement might be significantly reduced in PD subjects (Breniere, Do, & Bouisset, 1987; Elble, Moody, & Leffler, 1994; Nocera et al., 2013). This leads to an extension of the first swing phase and to a decrease in the length of the first step and in the walking speed (Yiou et al., 2012). In this study, the mean values of CoP_{ML} also decreased in PD subjects, as was observed in the studies by Yiou et al. (2012) and Nocera et al. Also, the mean values of Vel_{AP} and Vel_{ML} found were less in PD subjects, which is in line with those obtained by Halliday et al. (1998) and Gantchev et al. (1996). Deficits in APAs of PD subjects have been linked to abnormal muscle activation patterns characterized by an extension of excitatory and reduced inhibitory activity as well as a delay in its onset or even loss of muscular activation or deactivation (Crenna et al., 2006; Crenna & Frigo, 1991).

Besides the nonexistence of statistically significant differences between the healthy and PD subjects, no variable was significantly influenced by the dual-task condition in the PD group. These findings are surprising considering the frequent and consistent negative effect of dual-task on motor performance in PD subjects (Bloem, Grimbergen, van-Dijk, & Munneke, 2006; Holmes et al., 2010a; Yiou et al., 2012). Some authors have postulated that the nature of

TABLE 1. Comparison of the Sociodemographic and Individual Variables Between the Two Groups

	Healthy subjects	Parkinson's subjects	p-value
	M (SD)	M (SD)	
Age (years)	63.70 (2.42)	66.00 (2.74)	0.252*
Male, n (%)	5 (50)	6 (66.7)	0.463**
Education (years)	8.20 (1.43)	7.67 (1.69)	0.696*
Weight (Kg)	72.90 (3.14)	69.33 (4.20)	1.000*
Height (m)	1.64 (0.03)	1.65 (0.03)	0.931*
MoCA	26.50 (1.58)	24.78 (5.57)	0.095*
Stroop test: N° of named colours	24.30 (5.19)	18.17 (5.21)	0.035
Stroop test: N° of Errors	0.63 (0.49)	1.18 (1.45)	0.968*
Hoehn and Yahr scale			
Stage 1, n (%)		3 (33.3)	—
Stage 1.5, n (%)		3 (33.3)	—
Stage 2, n (%)		1 (11.1)	—
Stage 2.5, n (%)		2 (22.2)	—
Years of PD		10.22 (5.389)	—

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 and

** chi-square test

M – Mean, SD – Standard deviation

this neurodegenerative disease and the cognitive demands of a dual-task condition would limit the performance of one or both tasks (Morris, 2000; Rogers et al., 2011). Thus, before doing this study, it was expected that in GI, the motor performance of the PD subjects would be altered, even in individuals at the initial stage of the disease. Nevertheless, a nonsignificant difference between the single- and dual-task conditions in GI of PD subjects was also observed in the study by Nocera Nocera et al. (2013).

The nonexistence of significant differences between groups obtained in the present study suggests that the PD sample was able to prioritize the motor task in detriment of the cognitive task. This was evidenced by the number of colors correctly named, which was significantly lower in the PD subjects than in the healthy subjects. It is important

to note that no differences occurred between the two groups in terms of education and the MoCA test (Kelly et al., 2012b; Souza, Voos, Francato, Chien, & Barbosa, 2013). The MoCA test was applied to both groups to give an indication whether the subjects had cognitive deterioration or not and to detect differences of cognitive deterioration between the PD group and the healthy controls before the evaluation, to validate the findings and conclusions of the present study.

Moreover, the lack of differences between the healthy and PD subjects may be due to the fact that the underlying anticipatory muscular synergy was preserved and the lower CoP displacement and velocity was probably related to the slowness of execution (i.e., to bradykinetic episodes; Berardelli, Rothwell, Thompson, & Hallett, 2001). In fact, this

Table 2. Comparisons between the scores of single- and dual-task conditions for each group. The results are given as the mean (standard deviation), and the significant values ($p < 0.05$) are in bold.

	Healthy Subjects (n = 10)		Parkinson's subjects (n = 9)		Between Groups			Within Group	
	Single-task	Dual-task	Single-task	Dual-task	df	F	Effect Sizes η_p^2	Effect Sizes Healthy Group d	Effect Sizes Parkinson's Group d
CoP _{AP} [cm]	18.08 (11.54)	14.09 (9.65)	10.67 (5.47)	12.83 (7.04)	1,6	1.14	0.07	0.38	0.34
CoP _{ML} [cm]	24.16 (12.57)	28.69 (18.54)	23.65 (12.58)	25.76 (13.04)	1,6	0.03	0.00	0.29	0.16
Duration _{AP} [s]	0.31 (0.11)	0.21 (0.10)	0.26 (0.17)	0.18 (0.08)	1,6	0.36	0.02	0.95	0.60
Duration _{ML} [s]	0.22 (0.04)	0.17 (0.07)	0.25 (0.05)	0.32 (0.11)	1,6	12.49	0.44	0.88	0.82
Vel _{AP} [cm/s]	65.67 (53.88)	75.42 (48.81)	61.62 (48.05)	74.60 (35.83)	1,6	0.01	0.00	0.20	0.31
Vel _{ML} [cm/s]	107.09 (47.51)	166.16 (92.33)	98.73 (54.79)	96.65 (76.73)	1,6	1.43	0.08	0.80	0.03

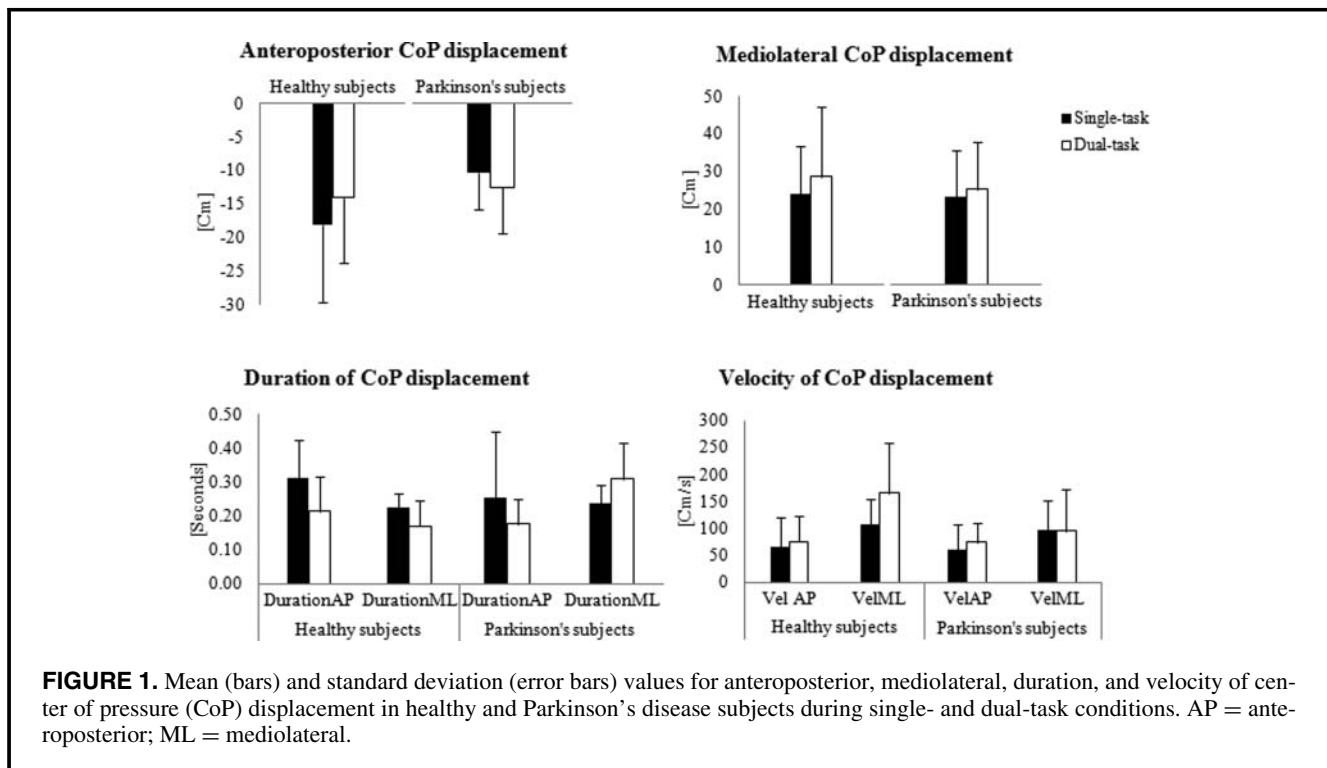


FIGURE 1. Mean (bars) and standard deviation (error bars) values for anteroposterior, mediolateral, duration, and velocity of center of pressure (CoP) displacement in healthy and Parkinson's disease subjects during single- and dual-task conditions. AP = anteroposterior; ML = mediolateral.

study found that the CoP_{ML} duration was longer and significantly different for the PD subjects than the healthy subjects. Furthermore, for the healthy subjects the postural phase duration increased in the dual-task condition in relation to the single-task condition. Also these results corroborate other studies suggesting that PD subjects have a lower CoP_{AP} , a higher duration of the postural phase, and that the APAs start later during GI in the dual-task condition than in the single-task condition (Carpinella et al., 2007; Nocera et al., 2013; Yiou et al., 2012).

In the same subjects, the CoP_{AP} duration tends to decrease from the single- to dual-task conditions. This decrease has been described as an ineffective strategy for maintaining balance, as it causes decreased backward CoP displacements, resulting in higher risk of falls (Holmes et al., 2010a; Kelly et al., 2012a; Nocera et al., 2013; Schmit et al., 2005). The fact that the PD subjects under study did not show any differences between the single- and dual-task conditions can also be explained by a greater focus on the motor task, which means that the motor performance is not debilitated despite the worse results in the Stroop test.

In the literature, most studies to characterize the motor deficits in PD subjects have used subjects in advanced stages of the disease and only in the single-task condition. However, most activities of daily living require the simultaneous execution of a cognitive task. Nevertheless, differences between durations were found. In particular, this study indicates that the behavior of individuals in the early stages of PD may retain the ability to prioritize tasks and choose the motor task in detriment of the cognitive task. However,

it is necessary understand if this prioritization is automatic or it is caused consciously by the individual to prevent falls. Therefore, future studies related to the stage of disease in the performance of motor and cognitive tasks independently and simultaneously are essential to clarify this doubt.

Clinical Relevance

This study corroborated that subjects with PD take longer to perform mediolateral displacements, especially in dual-task condition. On the other hand, the mediolateral and anteroposterior displacements found in the subjects with PD were similar to the ones found in the controls. These results indicate that in the early stages of PD, the cognitive performance can be impaired when performing cognitive motor dual tasks. Thus, the interventions should not be only focused on the motor performance, which is currently considered the main attention of the interventions, but should also include cognitive training.

Limitations

This study had some limitations. First, the small sample size and the sampling method can limit the results in regard to generalizations, that which leads us to consider it as an exploratory study. Second, the potential interference of the experimental environment on the GI of the subjects studied could affect the results obtained. Hence, further studies with larger samples and in different experimental environments are needed.

FUNDING

This research was carried out with the support and contribution of the Ângela Fernandes's PhD grant from Instituto Politécnico do Porto and Escola Superior de Tecnologia da Saúde, in Portugal.

REFERENCES

- Berardelli, A., Rothwell, J. C., Thompson, P. D., & Hallett, M. (2001). Pathophysiology of bradykinesia in Parkinson's disease. *Brain and Cognition, 124*, 2131–2146. 10.1093/brain/124.11.2131
- Bloem, B. R., Grimbergen, Y. A., van-Dijk, J. G., & Munneke, M. (2006). The "posture second" strategy: a review of wrong priorities in Parkinson's disease. *Journal of Neurology Science, 248*, 196–204. 10.1016/j.jns.2006.05.010
- Breniere, Y., Do, M. C., & Bouisset, S. (1987). Are dynamic phenomena prior to stepping essential to walking. *Journal of Motor Behavior, 19*, 62–76. 10.1080/00222895
- Burleigh-Jacobs, A., Horak, F. B., Nutt, J. G., & Obeso, J. A. (1997). Step initiation in Parkinson's disease: influence of levodopa and external sensory triggers. *Movement Disorders, 12*, 206–215. 10.1002/mds.870120211
- Caderbya, T., Dalleau, G., Leroyera, P., Bonazzia, B., Chanetengb, D., & Doc, M.-C. (2013). Does an additional load modify the anticipatory postural adjustments in Gait initiation? *Gait & Posture, 37*, 144–146. 10.1016/j.gaitpost.2012.06.012
- Carpinella, I., Crenna, P., Calabrese, E., Rabuffeti, M., Mazzoleni, P., Nenni, R., & Ferrarin, M. (2007). Locomotor function in the early stage of Parkinson's disease. *IEEE Engineering in Medicine and Biology Society, 15*, 543–551. 10.1109/TNSRE.2007.908933
- Chou, K. L., Amick, M. M., Brandt, J., Camicioli, R., Frei, K., Gitelman, D., . . . Uc, E. Y. (2010). A recommended scale for cognitive screening in clinical trials of Parkinson's disease. *Movement Disorders Journal, 25*, 2501–2507.
- Crenna, P., Carpinella, I., Rabuffetti, M., Rizzone, M., Lopiano, L., Lanotte, M., & Ferrarin, M. (2006). Impact of subthalamic nucleus stimulation on the initiation of gait in Parkinson's disease. *Experimental Brain Research, 172*, 519–532. 10.1007/s00221-006-0360-7
- Crenna, P., & Frigo, C. (1991). A motor programme for the initiation of forward-oriented movements in humans. *Journal of Physiology, 437*, 635–653.
- Doherty, M. (1994). Probability versus non-probability sampling in sample surveys. *The New Zealand Statistics Review, 1994*, 21–28.
- Elble, R. J., Moody, C., & Leffler, K. (1994). The initiation of normal walking. *Movement Disorders, 9*, 139–146. 10.1002/mds.870090203
- Gantchev, N., Viallet, F., & Aurenty, R. (1996). Impairment of posturokinetic co-ordination during initiation of forward oriented stepping movements in Parkinsonian patients. *Electroencephalography and Clinical Neurophysiology, 101*, 110–120. 10.1016/0924-980X(95)00253-H
- Hall, L. M., Brauer, S. G., Horak, F., & Hodges, P. W. (2013). The effect of Parkinson's Disease and levodopa on adaptation of anticipatory postural adjustments. *Neuroscience, 250*, 483–492. 10.1016/j.neuroscience.2013.07.006
- Halliday, S. E., Winter, D. A., Frank, J. S., Patla, A. E., & Prince, F. (1998). The initiation of gait in young, elderly, and Parkinson's disease subjects. *Gait and Posture, 8*, 8–14. 10.1016/S0966-6362(98)00020-4
- Hanke, A., & Rogers, W. (1992). Reliability of ground reaction force measurements during dynamic transitions from bipedal to single-limb stance in healthy adults. *Physical Therapy, 72*, 810–816.
- Hausdorff, J. M., Doniger, G. M., Springer, S., Yogev, G., Simon, E. S., & Giladi, N. (2006). A common cognitive profile in elderly fallers and in patients with Parkinson's disease: the prominence of impaired executive function and attention. *Experimental Aging Research, 32*, 411–429. 10.1080/03610730600875817
- Hiraoka, K., Matsuo, Y., & Abe, K. (2005). Soleus H-Reflex Inhibition during gait initiation in Parkinson Disease. *Movement Disorders, 20*, 858–864.
- Hiraoka, K., Matsuo, Y., Iwata, A., Onishi, T., & Abe, K. (2006). The effects of external cues on ankle control during gait initiation in Parkinson's disease. *Parkinsonism and Related Disorders, 12*, 97–102.
- Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: onset, progression and mortality. *Neurology, 17*, 427–442. 10.1371/journal.pone.0069237
- Holmes, J. D., Jenkins, M. E., Johnson, A. M., Adams, S. G., & Spaulding, S. J. (2010). Dual-task interference: The effects of verbal cognitive tasks on upright postural stability in Parkinson's disease. *Parkinson's Disease, 2010*, 696492. 10.4061/2010/696492
- Hoops, S., Nazem, S., Siderowf, A. D., Duda, J. E., Xie, S. X., Stern, M. B., & Weintraub, D. (2009). Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease. *Neurology, 73*, 1738–1745. 10.1212/WNL.0b013e3181c34b47
- Kelly, V. E., Eusterbrock, A. J., & Shumway-Cook, A. (2012a). The effects of instructions on dual-task walking and cognitive task performance in people with Parkinson's disease. *Parkinson's Disease, 2012*, 671261. 10.1155/2012/671261
- Kelly, V. E., Eusterbrock, A. J., & Shumway-Cook, A. (2012b). A review of dual-task walking deficits in people with Parkinson's disease: motor and cognitive contributions, mechanisms, and clinical implications. *Parkinson's Disease, 2012*, 918719. 10.1155/2012/918719
- Morris, M. (2000). Movement disorders in people with Parkinson's disease: A model for physical therapy. *Physical Therapy, 80*, 578–597.
- Mullineaux, D., Bartlett, R., & Bennett, S. (2001). Research design and statistics in biomechanics and motor control. *Journal of Sports Sciences, 19*, 739–760. <http://dx.doi.org/10.1080/026404101317015410>
- Nocera, J. R., Roemmich, R., Elrod, J., Altmann, L. J. P., & Hass, C. J. (2013). Effects of cognitive task on gait initiation in parkinson disease: Evidence of motor prioritization? *Journal of Rehabilitation Research & Development, 50*, 699–708 <http://dx.doi.org/ORG/10.1682/JRRD.2012.06.0114>
- Pate, R., Pratt, M., Blair, S. N., Haskell, W., Macera, C., Bouchard, C., . . . Wilmore, J. H. (1995). Physical activity and public health: A recommendation from the centers for disease control and prevention and the american college of sports medicine. *JAMA, 273*, 402–407.
- Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society, 39*, 142–148.
- Rogers, M. W., Kennedy, R., Palmer, S., Pawar, M., Reising, M., Martinez, K. M., . . . MacKinnon, C. D. (2011). Postural preparation prior to stepping in patients with Parkinson's disease. *Journal of Neurophysiology, 106*, 915–924. 10.1152/jn.00005.2010
- Romann, A. J., Dornelles, S., Maineri, N. D. L., Rieder, C. R. D. M., & Olchik, M. R. (2012). Cognitive assessment instruments

- in Parkinson's disease patients undergoing deep brain stimulation. *Dementia e Neuropsychologia*, 6, 2–11.
- Schmit, J. M., Riley, M. A., Dalvi, A., Sahay, A., Shear, P. K., Shockley, K. D., & Pun, R. Y. K. (2005). Deterministic center of pressure patterns characterize postural instability in Parkinson's disease. *Experimental Brain Research*, 168, 357–367. 10.1007/s00221-005-0094-y
- Sethi, V., & Raja, R. (2012). Effects of dual task training on balance and activities of Daily Livings (ADLs) in patients with Parkinsonism. *International Journal of Biological & Medical Research*, 3, 1359–1364.
- Shiratori, T., & Latash, M. L. (2001). Anticipatory postural adjustments during load catching by standing subjects. *Clinical Neurophysiology*, 112, 1250–1265. 10.1016/S1388-2457(01)00553-3
- Souza, C. O., Voos, M. C., Francato, D. V., Chien, H. F., & Barbosa, E. R. (2013). Influence of educational status on executive function and functional balance in individuals with Parkinson disease. *Cognitive Behavioral Neurology*, 26, 6–13.
- Tsukahara, A., Kawanishi, R., Hasegawa, Y., & Sankai, Y. (2010). Sit-to-stand and stand-to-sit transfer support for complete paraplegic patients with robot suit HAL. *Advanced Robotics*, 24, 1615–1638. 10.1163/016918610x512622
- Tsutiya, N., Christovão, T. C. L., Grecco, L. A. C., Costa, R. V., Oliveira, C. S., & Monteiro, F. F. (2011). Comparative analysis of postural balance in elderly individuals with and without Parkinson's disease. *Unopar Científica Ciências Biológicas e da Saúde*, 13, 181–185.
- Winter, D. (2009). *Biomechanics and motor control of human movement* (4th ed.). New York, NY: Wiley.
- Wu, T., & Hallett, M. (2009). Dual task interference in Parkinson's disease. *US Neurology*, 5, 30–33.
- Yiou, E., Caderby, T., & Hussein, T. (2012). Adaptability of anticipatory postural adjustments associated with voluntary movement. *World Journal of Orthopedics*, 3(6), 75–86. 10.5312/wjo.v3.i6.75.
- Yogev-Seligmann, G., Rotem-Galili, Y., Mirelman, A., Dickstein, R., Giladi, N., & Hausdorff, J. (2010). How does explicit prioritization alter walking during dual-task performance? Effects of age and sex on gait speed and variability. *Physical Therapy*, 9, 1–10. 10.2522/ptj.20090043

Received March 6, 2015

Revised September 17, 2015

Accepted October 2, 2015