Title: Influence of dual-task on sit-to-stand-to-sit postural control in Parkinson's disease

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Abstract

Postural control deficits are the most disabling aspects of Parkinson's disease (PD), resulting in decreased mobility and functional independence. The aim of this study was to assess the postural control stability, revealed by variables based on the centre of pressure (CoP), in individuals with PD while performing a sit-to-stand-to-sit sequence under single- and dual-task conditions.

An observational, analytical and cross-sectional study was performed. The sample consisted of 9 individuals with PD and 9 healthy controls. A force platform was used to measure the CoP displacement and velocity during the sit-to-stand-to-sit sequence. The results were statistically analysed.

Individuals with PD required greater durations for the sit-to-stand-to-sit sequence than the controls ($p<0.05$). The anteroposterior and mediolateral CoP displacement were higher in the individuals with PD ($p<0.05$). However, only the anteroposterior CoP velocity in the stand-to-sit phase ($p=0.006$) was lower in the same individuals. Comparing the single- and dual-task conditions in both groups, the duration, the anteroposterior CoP displacement and velocity were higher in the dual-task condition ($p<0.05$).

The individuals with PD presented reduced postural control stability during the sit-to-stand-to-sit sequence, especially when under the dual-task condition. These individuals have deficits not only in motor performance, but also in cognitive performance when performing the sit-to-stand-to-sit sequence in their daily life tasks. Moreover, both deficits tend to be intensified when two tasks are performed simultaneously.

Keywords: Dual-task; Parkinson's; Postural Control; Sit-to-Stand-to-Sit.

1. INTRODUCTION

Parkinson's disease (PD) is considered the second most common neurodegenerative disorder, affecting about 1% of the world's current population (1, 2). Some projections indicate a large increase of this prevalence over the coming decades (2).

At the moment, the aetiology is explained by genetic predisposition and the presence of toxic environmental factors (3, 4). The majority of individuals with PD present an inadequate interaction between systems responsible for body balance, including the vestibular, visual and proprioceptive systems. Consequently, these individuals tend to shift their centre of gravity forward, and therefore, have difficulty to perform compensatory movements to require balance (5). The transition from sitting to standing and standing to sitting are components of some everyday functional tasks that are highly demanding from a postural control perspective. In fact, the sit-to-stand-to-sit (STSTS) sequence implies the involvement of anticipatory postural adjustments (APAs) to movement performance (6-8). Hence, the study concerning the STSTS sequence can contribute to clarify postural control requirements during daily activities. The variability and efficiency of functional movements require an appropriate postural control that depends on APAs to maintain stability of internal and external disturbances, taking into account the context and the task (9). The planning of APAs involves various structures of the central nervous system (CNS), such as the pre-motor cortex, supplementary motor area, basal ganglia and cerebellum (10, 11) that, through independent channels, convey information to the reticular formation, such as the pedunculopontine nucleus, which is important to modulate the APAs (12). The neural connection between the basal ganglia and the pedunculopontine nucleus is through the corticostriatal-pallidum-pedunculopontine circuit, which is compromised in individuals with PD leading to postural control deficits. This is manifested in the changes in the activation of postural

muscles in the form of APAs (10, 13-15). As the CNS is responsible for the motor modulation circuits, which are compromised in individuals with PD, there is a decrease in postural control and consequently, repercussions in the performance of tasks, like STSTS sequences (16-18). This decreased postural control was demonstrated through CoP displacement variables. The CoP displacement reflects the orientation of body segments and corrective responses that control the centre of mass over the base of support (19), resulting from the combination of descending motor commands and the mechanical properties of the surrounding muscles (20). In situations of dual-task, the use of cortical resources to perform motor tasks can affect or influence the performance of one or both tasks (21-23). Despite the importance of the postural control stability for the STSTS sequence performance and the impact of PD on the postural control system, few studies have assessed these issues and only the sit-to-stand sequence has been addressed. Additionally, no study has evaluated this task under high cognitive demanding conditions. Based on these facts, the objective of the present study was to analyse the postural control stability in individuals with PD in single- and dual-task conditions. More specifically, the postural stability was assessed through representative CoP displacement variables in the anteroposterior and mediolateral directions (displacements and velocities), in the five phases of the STSTS sequence in single- and dual-task conditions. Based on the results obtained by Bhatt et al. (16) and on the neural dysfunction involving postural control pathways, a reduced postural control stability in individuals with PD can be hypothesised during the preforming of the STSTS sequence. This reduced stability would be amplified in these individuals when the STSTS sequence is performed in the dual-task condition.

2. MATERIALS AND METHODS

2.1. Study Design and Participants

A cross-sectional study was implemented using a non-probabilistic (24) sample of 9 individuals with PD and 9 healthy controls, aged between 52 and 80 years old. The individuals diagnosed with PD were patients from the Parkinson's Association, Porto, in Portugal, while the healthy controls were community-dwelling volunteers, mainly from Porto.

Subjects were excluded if they presented one of the following criteria: severe cognitive impairment (screened using the Montreal Cognitive Assessment (MoCA) test (25)); incapable of performing the sit-to-stand or stand-to-sit sequence independently; and unable to speak. Severely disabled PD patients (> 3 Hoehn and Yahr scale (26)), patients diagnosed with any other neuromuscular disease, and those who had undergone deep brain stimulation through subthalamic surgery or were taking cholinergic medication were also excluded. Healthy controls that had been diagnosed as adults with any neuromuscular disorder or that could not be considered sedentary according to the Centre for Disease Control for the American College of Sports Medicine, were also excluded (27).

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

2.2. Instruments

The data collected from all participants included the sociodemographic characteristics age, gender, height, weight and level of education, and years of disease, cognitive performance (assessed using the MoCA test), Hoehn and Yahr scale and the CoP data

101 acquired using a force platform (model FP4060-8 from Bertec Corporation (USA))
102 under the single- and dual-task conditions.
103 The scale of Hoehn & Yahr (1967) evaluates the severity of overall dysfunction in
104 individuals with PD. It is a 7-point scale, in which each point represents a different
105 stage of the disease (stages 1 to 5, including 1.5 and 2.5). The scale increases with the
106 severity of dysfunction along with the stage of the disease (26). The MoCA test consists
107 of eight fields: visuospatial, nomination, memory, attention, language, abstraction,
108 deferred evocation and orientation. The performance of an individual is calculated by
109 the addition of the scores obtained in each of the domains, and the maximum that can be
110 reached is equal to 30 points (25, 28).
111 For the evaluation of the postural control, the data from the force platform was acquired
112 at a sampling rate of 1000 Hz (29). The platform was connected to a Bertec AM 6300
113 amplifier (USA) and in turn, this was connected to an analog-digital converter from
114 Biopac Systems, Inc. (USA), and to an analog board of Qualysis Track Manager
115 (Sweden) that can be used for stabilometric analyses. The stabilometric measurements
116 comprise the assessment of balance in the orthostatic position through body movements,
117 taking into account the anteroposterior (Fx), mediolateral (Fy) and vertical (Fz)
118 components of the ground reaction force. For this, it is necessary to monitor the
119 movement of the CoP in the anteroposterior (CoPAP) and mediolateral (CoPML)
120 directions (30). The signal related to the CoP movement was filtered using a fourth-
121 order Butterworth low pass filter with a cut-off frequency of 20 Hz (31).
122 The attention level and consequently, the motor control perturbations were attained
123 through a cognitive secondary task, namely the Stroop colour word test. This test
124 consists in the enunciation of the visual colour instead of the written one. The number

of errors and the number of named items were used for analysis (32) during a pre-defined time (60 seconds) for both groups.

2.3. Procedures

After an explanation of all the procedures involved, all individuals performed the study with shorts and standard shoes (33). The height of the chair seat was adjusted to 100% of the lower leg length (from the knee joint to the ground), and 2/3 of the femur supported on the seat was used as a reference for the subjects to be considered in the sitting position. In the single-task condition, the subjects were asked to rise from sitting with a self-selected speed without using their upper limbs (34), then remain for 60 seconds in the standing position, looking at a point two meters away at eye level. After this interval, subjects were instructed to sit, again without any kind of support and at a self-selected speed. In the dual-task condition, all the previous procedures were repeated; however, the subjects were required to perform the Stroop test during the performing of the STSTS sequence (28). The test words in different colours were projected on a wall at eye level. The subjects were instructed to name the colour instead of reading the word and no other specific instructions were given. The words were present according to each participant's responses during a pre-defined period of 60 seconds. A one minute rest between each trial was allowed, and the necessary repetitions were performed in order to obtain three valid trials for each subject.

The CoP displacement variables were analysed over the five phases of the STSTS sequence. For this, the sit-to-stand-to sit sequence was divided into five phases: sitting phase - phase 1, sit-to-stand phase - phase 2, standing phase - phase 3, stand-to-sit phase - phase 4, and sitting phase - phase 5. The procedures used to identify the phases are shown in Table 1.

150 < Insert Table 1 about here >

151

152 The data acquisition was always performed by the same investigator to ensure the
153 reproducibility of the procedures. The data analysis was performed using the Matlab
154 software (MathWorks, USA) and Acqknowledge software (Biopac Systems, Inc. USA).

155

156 **2.4. Statistical Analysis**

157 Descriptive statistical analyses were performed using proportions and measures of
158 central tendency and dispersion.

159 The independent sample t test and Chi square test were performed to examine whether
160 there were significant differences between the groups in terms of the sociodemographic
161 and anthropometric variables. The multiple analysis of variance (MANOVA) test was used
162 to analyse the interaction between the groups (PD and controls) and the conditions
163 (single- and dual-task). The Bonferroni analysis was used as a post-hoc test to
164 determine the differences in single- and dual- task conditions in each group and to
165 determine for each condition the differences between the groups (PD and controls). The
166 number of errors and the number of correctly named items for the Stroop test were used
167 as covariates in the analysis. Two-tailed tests were used in all analyses, and $p < 0.05$
168 was adopted for statistical significance. All statistical analyses were conducted using
169 IBM SPSS Statistics 22.0 (SPSS, Inc., Chicago, IL, USA).

170

171 **3. RESULTS**

172 The 9 PD individuals (66.7% male) had a mean age of 66 years old (standard deviation
173 (SD) = 8.2), a mean education of 7.7 years (SD = 5.6) and a mean number of years with
174 PD 10.22 (SD 5.38). Most of these participants were classified in stage 1 and 1.5 of the

Hoehn and Yahr scale. The 9 healthy controls (44.4% male) had a mean age of 63.9 years (SD = 8.1) and a mean education of 7.8 years (SD = 4.6). The Mann-Whitney test and chi-square test showed no significant differences between the two groups studied, Table 2.

< Insert Table 2 about here >

The MANOVA test showed that in phase 1, no significant differences were found between the groups (between-subjects) or conditions (within-subjects) and also no significant interaction was found between group and condition, Table 3.

< Insert Table 3 about here >

In phase 2, a significant difference between the groups was found. The individuals with PD presented a greater duration ($p=0.047$) compared to the healthy controls. The Post-hoc analysis showed that these differences occurred only in the dual-task condition ($p=0.005$). However, no differences between conditions or any significant interaction between groups and conditions were found.

In phase 3, the differences between groups were found in terms of the duration and CoPAP displacement. The duration was significantly greater in the PD individuals than in the healthy controls ($p<0.001$). These differences occurred both under single- ($p<0.001$) and dual-task ($p=0.004$) conditions. The CoPAP displacement was significantly higher in the individuals with PD in comparison to the healthy controls (0.015). The Post-hoc analysis showed that these differences occurred under the dual-

task condition (p=0.021). No differences between the tasks or any significant interaction between group and condition were found.

In phase 4, the differences between the two groups occurred in the duration, CoPML displacement and CoPAP velocity. The duration was significantly greater in the individuals with PD than in the healthy controls ($p<0.001$). Relative to the healthy controls, the CoPML displacement was significantly higher (p=0.036) and the CoPAP velocity was significantly lower (p=0.006) in the individuals with PD. The Post-hoc analysis showed that these differences occurred both under the single and dual-task conditions, except in terms of the CoPML displacement that occurred only in the dual-task condition (p=0.015). Also, differences between the two conditions were found in the duration, with a longer duration in the dual- than in the single-task condition (p=0.009). The Post-hoc analysis showed that these differences occurred in the group with PD (p=0.004). Finally, no significant interaction between group and condition were found.

In phase 5, only the COPAP displacement had differences between the two groups, with higher values for the individuals with PD in comparison to the healthy controls. However, significant differences were found between the conditions for the CoPAP displacement (p= 0.043) and velocity (0.010), with higher values for the dual-task condition. Also, no significant interaction between group and condition was found in terms of the duration and CoPAP velocity, which seems to indicate that the differences in the duration and CoPAP velocity were caused by the disease (PD).

The estimated marginal means of the conditions and groups is presented in Figure 1.

< Insert Figure 1>

4. DISCUSSION

This study reveals significant differences regarding the postural control of individuals with PD. It is clear that there is a relationship between performing the STSTS sequence and performing a cognitive task.

Comparing the individuals with PD and the healthy controls studied as to the duration of each phase of the sit-to-stand-to-sit sequence, significant differences were found in the single- and dual-task conditions in phases 2, 3 and 4. This finding corroborates previous studies that show a significant increase in the duration of the phases of the STSTS sequence performed by individuals with PD (16). No difference in the duration of phase 1 was found in the study of Inkster (35), where the time to rise from a chair was not significantly different between individuals with PD (ON medication) and controls. The differences found in the duration of phases 2, 3 and 4 between the two groups in both the single- and dual-task conditions can be explained by the pathophysiology of PD. In phase 2, the individuals have to perform a sit-to-stand transfer and the greater duration of this transition in PD individuals compared to healthy controls could be due to the bradykinesia and rigidity present in individuals with PD. Phase 3 corresponds to a stabilization phase that rarely presents any postural deficits in PD. In phase 4, individuals have to control the postural muscles, including the soleus eccentric activity, which is a complex task for individuals with PD (14, 15).

Comparing the CoPAP and CoPML displacements between the individuals with PD and the healthy controls, significant differences were only found in the dual-task condition, with the former group showing higher CoPAP displacements and a weaker relation for the CoPML displacement. Individuals with PD have superior backward stability resulting from a more anterior CoP position at seat-off (16). Given these differences in movement patterns, individuals with mild to moderate severity of PD have an

exaggerated anticipatory response in the preparation phase in comparison to individuals without PD. This anticipatory response is manifested as an increased momentum that generates a greater forward CoP displacement (35). Furthermore, several studies have shown an altered function of the supplementary motor area in individuals with PD due to its indirect connections with the basal ganglia (36).

Compared to the healthy controls, the individuals with PD had a lower CoPAP velocity in the single-task condition in phases 3 and 4, and also a lower CoPML velocity in phase 3. During the STSTS sequences, these individuals demonstrated a large proportion of co-contraction because they move slower (37). However, individuals with PD compensate their slowness and related posterior instability by positioning their CoP forward at seat-off (38). The lower velocity could increase the likelihood of backward balance loss at seat-off because of its proximity to their limits of stability (39).

Comparing the single- and dual-task conditions, only significant differences were found in the CoPML velocity in phase 3. The few differences between the single- and dual-task conditions in individuals with PD may be due to the time of diagnosis of the PD of the individuals studied (10.22 ± 5.38 years), as they may have already acquired, over time, several strategies that assist in carrying out daily life tasks, such as the movements required during the STSTS sequence. These strategies can also justify the similarity with some findings obtained for healthy controls (40), as well as, the fact that the PD group only had a mild severity of the disease (median Hoehn & Yahr score of 1.5). However, a limitation of this study is that the groups did not perform the cognitive task (Stroop test) in the single-task condition. The priority of a task is closely related to several factors such as: the progression stage of the disease, complexity of the secondary task, limitation of attentional resources, motivational preference, internal vs. external attention, and postural confidence (22, 41, 42). So the assessment using the

Stroop test in the single-task condition could be helpful to determine the differences between the two groups at baseline. However, there are studies aimed to identify a number of factors in order to predict the Stroop performance. For example, one study found an inverse relationship between cognitive deficits and an increase of errors and therefore reduced the number of colours specified in the Stroop test (43). Other studies have found that the level of education is also a predictor for the Stroop performance (44). However, in this study, the cognitive impairment and educational level were taken into account. Individuals with cognitive impairment were not included in this study and there were no differences between the PD group and the healthy controls in terms of the performance of the MoCA test and of the educational level. Thus, although the Stroop test was not performed at baseline, it seems that the differences found in the dual-task condition are due to the introduction of the motor task. Nevertheless, this should be confirmed in future studies.

In this study, we found that the individuals with PD had greater difficulty in the stand-to-sit sequence, which has been ignored in current studies, than in the sit-to-stand sequence, especially in the dual-task condition. Biomechanical studies focusing on posture stability have shown that the performance of dual-task has a significant effect on the postural control in these individuals (45-48). This suggests that they create a restriction on APAs in order to focus on the cognitive task without losing the balance (22, 49, 50). Furthermore, recent studies with rehabilitative intervention in individuals with PD have shown promising results. The reported results indicate a potential for reversing or slowing the progression of the disease, demonstrating that the ability to learn is relatively well preserved (51). Several studies have shown that the dual-task cognitive-motor training has a positive effect on gait in the PD population; in particular, in terms of the gait speed, variability and step length (52, 53).

Conclusion

The individuals with PD presented reduced postural stability for most of the phases of the STSTS sequence, and this stability was most impaired in the dual-task condition. These findings may suggest that this postural control deficit could lead to compensatory motor strategies in the lower extremities. However, further studies concerning the impact of reduced stability during the STSTS sequence in individuals with PD and their compensatory motor strategies are required.

This study also provides data and guidelines for future research, as well as pointing out the importance of cognitive training. Based on our findings that are in-line with the ones reported by other authors (54-56), it is expected that the stimulation of the cognition can help achieve improvements in terms of motor task performance.

Conflict of Interest Statement

The authors report no conflict of interest.

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REFERENCES

1. Andlin-Sobocki P, Jonsson B, Wittchen H, Olesen J. Cost of disorders of the brain in Europe. Eur J Neurol. 2005;12(1):1-27.

2. Campenhausen S, Bornschein B, Wick R, Botzel K, Sampaio C, Poewe W. Prevalence and incidence of Parkinson's disease in Europe. Eur Neuropsychopharmacol. 2005;15(4):473-90.

3. Levy G, Louis ED, Cote L, Perez M, Mejia-Santana H, Andrews H, et al. Contribution of aging to the severity of different motor signs in Parkinson disease. Arch Neurol. 2005;62(3):467-72.

4. Huang Z, Fuente-Fernández R, Stoessl AJ. Etiology of Parkinson's Disease. Can J Neurol Sci. 2003;30(1):10-8.

5. Smania N, Picelli A, Geroin C, Ianes P, Marchina EL, Zenorini A, et al. Balance and Gait Rehabilitation in Patients with Parkinson's Disease Neurorehabilitation and Neural Repair Journal. 2010;24(9):826-34.

6. Janssen WGM, Bussmann HBJ, Stam HJ. Determinants of the Sit-to-Stand Movement: A Review. Phys Ther. 2002;82(9):866-79.

7. Duncan RP, Leddy AL, Earhart GM. Five Times Sit-to-Stand Test Performance in Parkinson's Disease. Arch Phys Med Rehabil. 2011;92(9):1431-6.

8. Mazza C, Zokb M, Croce UD. Sequencing sit-to-stand and upright posture for mobility limitation assessment: determination of the timing of the task phases from force platform data Gait Posture. 2005;21(4):425-31.

9. Aruin AS. The organization of anticipatory postural adjustments. Journal of Automatic Control. 2002;12(1):31-7.

10. Jacobs JV, Lou JS, Kraakevik JA, Horak FB. The supplementary motor area contributes to the timing of the anticipatory postural adjustment during step initiation in participants with and without Parkinson's disease. Neuroscience. 2009;164(2):877-85.

11. Timmann D, Horak F. Perturbed step initiation in cerebellar subjects: 2. Modification of anticipatory postural adjustments. Exp Brain Res. 2001;141(1):110-20.

12. Schepens B, Drew T. Independent and convergent signals from the pontomedullary reticular formation contribute to the control of posture and movement during reaching in the cat. J Neurophysiol. 2004;92(4):2217-38.

13. Purves D, Augustine G, Fitzpatrick D, Hall W, Sanuellamantia A, Mcnamara J, et al. Neurocience. 3 ed. U.S.A.: Sunderland; 2004.

14. Shumway-Cook A, Woollacott MH. Motor control: translating research into clinical practice. Wolters Kluwer Health. 2007.

15. Karachi C, Grabli, D., Bernard FA, Tandé D, Wattiez N, Belaid H, François C. Cholinergic mesencephalic neurons are involved in gait and postural disorders in Parkinson Disease. The Journal of clinical investigation. 2010;120(8):2745-54.

16. Bhatt T, Yang F, Mak MKY, Hui-Chan CW-Y, Pai Y-C. Effect of Externally Cued Training on Dynamic Stability Control During the Sit-to-Stand Task in People With Parkinson Disease. J Am Phys Ther Assoc. 2013;93(4):492-503.

17. O'Shea S, Morris ME, Iansek R. Dual task interference during gait in people with Parkinson disease: effects of motor versus cognitive secondary tasks. Phys Ther. 2002;82(9):888-97.

18. Tsukahara A, Kawanishi R, Hasegawa Y, Sankai Y. Sit-to-Stand and Stand-to-Sit Transfer Support for Complete Paraplegic Patients with Robot Suit HAL. Advanced Robotics. 2010;24(11):1615–38.

19. Prieto T, Myklebust J, Hoffmann R, Lovett E, Myklebust B. Measures of postural steadiness: differences between healthy young and elderly adults. Biomed Eng (NY). 1996;43(9):956-66.

20. Baratto L, Morasso P, Spada G. A new look at posturographic analysis in the clinical context: sway-density versus other parameterization techniques. Motor Control. 2002;6(3):246-70.

21. Wu T, Hallett M. Dual Task Interference in Parkinson's Disease. US Neurology. 2009.

22. Holmes J, Jenkins M, Johnson A, Adams S, Spaulding S. Dual-task interference: the effects of verbal cognitive tasks on upright postural stability in Parkinson's disease. Parkinsons Dis. 2010;69(6):49-52.

23. Kelly V, Eusterbrock A, Shumway-Cook A. The effects of instructions on dual-task walking and cognitive task performance in people with Parkinson's Disease. Parkinson´s Disease. 2012;2012:1-9.

24. Creswell JW, Clark VLP. Designing and Conducting: Mixed Methods Research. 2 ed. USA: SAGE Publications; 2011.

25. Hoops S, Nazem S, Siderowf AD, Duda JE, Xie SX, Stern MB, et al. Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease. Neurology. 2009;73(21):1738-45.

26. Hoehn MM, Yahr MD. Parkinsonism: onset, progression and mortality. Neurology. 1967;17(5):427-42.

27. Thompson W. ACSM's Guidelines for Exercise Testing and Prescription. 8 ed. Lippincott: Williams & Williams; 2001.

28. Romann AJ, Dornelles S, Maineri NdL, Rieder CRdM, Olchik MR. Cognitive assessment instruments in Parkinson's disease patients undergoing deep brain stimulation. Dement Neuropsychol. 2012;6(1):2-11.

29. Hanke A, Rogers W. Reliability of ground reaction force measurements during dynamic transitions from bipedal to single-limb stance in healthy adults Phys Ther. 1992;72(11):810-6.

30. Geurts A, Nienhuis B, Mulder T. Intrasubject variability of selected force-platform parameters in the quantification of postural control. Arch Phys Med Rehabil. 1993;74(11):1144-50.

31. Schmid M, Confortoemail S, Camomilla V, Cappozzo A, D'Alessio T. The sensitivity of posturographic parameters to acquisition settings. Med Eng Phys. 2002;24(9):623-31.

32. Lezak MD, Howieson DB, Loring DW. Neuropsychological assessment. 4 ed. New York: Oxford University Press, Incorporated; 2004.

33. Kim M, Yi C, Yoo W, Choi B. EMG and Kinematics analysis of the trunk and lower extremity during sit-to-stand task while wearing shoes with different heel heights in healthy young women. Human Movement Science. 2011;30(3):596-605.

34. Dubost V, Beauchet O, Manckoundia P, Herrmann F, Mourey F. Decreased Trunk Angular Displacement During Sitting Down: An Early Feature of Aging. Phys Ther. 2005;85(5):404-12.

35. Inkster LM, Eng JJ. Postural control during a sit-to-stand task in individuals with mild Parkinson's disease. Exp Brain Res. 2004;154(1):33-8.

36. Cunnington R, Iansek R, Thickbroom GW, Laing BA, Mastaglia FL, Bradshaw JL, et al. Effects of magnetic stimulation over supplementary motor area on movement in Parkinson's disease. Brain Cogn. 1996;119(Pt 3):815-22.

421 37. Souza LAPS, Curtarelli MB, Mukherjee M, Dionisio VC. The effect of the
422 partially restricted sit-to-stand task on biomechanical variables in subjects with and
423 without Parkinson's disease. J Electromyogr Kinesiol. 2011;21(5):719–26.
424 38. Mancini M, Rocchi L, Horak FB, Chiari L. Effects of Parkinson's disease and
425 levodopa on functional limits of stability. Clinical Biomechanics. 2008;23(4):450-8.
426 39. Pai YC, Lee WA. Effect of a terminal constraint on control of balance during sit-
427 to-stand. Journal of Motor Behaviour. 1994;26(3):247–56.
428 40. Wulf G, Landers M, Leithwaite R, Tollner T. External focus instructions reduce
429 postural instability in individuals with Parkinson disease. Phys Ther. 2009;89:162–8.
430 41. Kelly VE, Eusterbrock AJ, Shumway-Cook A. A Review of Dual-Task Walking
431 Deficits in People with Parkinson's Disease: Motor and Cognitive Contributions,
432 Mechanisms, and Clinical Implications. Parkinson´s Disease. 2012;2012(918719):1-14.
433 42. Schaefer S. The ecological approach to cognitive–motor dual-tasking: findings
434 on the effects of expertise and age. Front Psychol. 2014;5(1167):1-9.
435 43. Van der Elst W, Van Boxtel M, Van Breukelen G, Jolles J. The Stroop Color-
436 Word Test Influence of Age, Sex, and Education; and Normative Data for a Large
437 Sample Across the Adult Age Range Assessment. 2006;13(1):62-79.
438 44. Ivnik RJ, Malec JF, Smith GE, Tangalos EG, Petersen RC. Neuropsychological
439 tests' norms above age 55: COWAT, BNT, MAE, Token, WRAT-R Reading,
440 AMNART, STROOP, TMT, and JLO. The Clinical Neuropsychologist.
441 1996;10(3):262–78.
442 45. Fama R, Sullivan E. Motor sequencing in Parkinson's disease: relationship to
443 executive function and motor rigidity. Cortex. 2002;38(5):753-67.

444 46. Springer S, Giladi N, Peretz C, Yogev G, Simon E, Hausdorff J. Dual-tasking
445 effects on gait variability: the role of aging, falls, and executive functions. Mov Disord.
446 2006;21(7):950-7.
447 47. Van-Lersel B, Kessels P, Bloem R, Verbeek A, Rikkert M. Executive functions
448 are associated with gait and balance in community-living elderly people. Journal of
449 Gerontology Series A Biological Sciences and Medical Sciences. 2008;63(12):1344-9.
450 48. Coppin A, Shumway-Cook A, Saczynski J, Patel K, Ble A, Ferrucci L.
451 Association of executive function and performance of dual-task physical tests among
452 older adults: analyses from the InChianti study. Age Ageing. 2006;35(6):619-24.
453 49. Nocera JR, Roemmich R, Elrod J, Altmann LJP, Hass CJ. Effects of Cognitive
454 Task on Gait Initiation in Parkinson Disease: Evidence of Motor Prioritization? J
455 Rehabil Res Dev. 2013;50(5):699-708
456 50. Marchese R, Bove M, Abbruzzese G. Effect of cognitive and motor tasks on
457 postural stability in Parkinson's disease: a posturographic study. Mov Disord.
458 2003;18(6):652–8.
459 51. Chiviacowsky S, Wulf G, Lewthwaite R, Campos T. Motor learning benefits of
460 self-controlled practice in persons with Parkinson's disease. Gait Posture.
461 2012;35(4):601-5.
462 52. Yogev-Seligmann G, Giladi N, Brozgol M, Hausdorff J. A Training Program to
463 Improve Gait While Dual Tasking in Patients With Parkinson's Disease: A Pilot Study.
464 Archive Physical Medicine Rehabilitation. 2011;20:176-81.
465 53. Sethi V, Raja R. Effects of Dual task training on balance and activities of Daily
466 Livings (ADLs) in patients with Parkinsonism. Int J Biol Med Res. 2012;3(3):1359-64.

54. Brauer SG, Woollacott M, Lamont R, Clewett S, O'Sullivan J, Silburn P. Single and dual task gait training in people with Parkinson's Disease: A protocol for a randomised controlled trial. BMC Neurol. 2011;11(90):1-6.

55. Hiyamizu M, Morioka S, Shomoto K, Shimada T. Effects of dual task balance training on dual task performance in elderly people: a randomized controlled trial. Clin Rehabil. 2011;26(1):58-67.

56. Vanshika S, Ravi R. Effects of Dual task training on balance and activities of Daily Livings (ADLs) in patients with Parkinsonism. International Journal of Biological & Medical Research. 2012;3(1):1359-64.

TABLE CAPTIONS

Table 1 – Procedures adopted to assess the phases of the sit-to-stand-to-sit sequence, based on Tsukahara et al. (18).

Table 2 – Comparison of the sociodemographic and anthropometric variables between the two groups under study.

Table 3 – Results of the MANOVA test with p-values of between-subjects, within-subjects and interaction for the duration of each phase and CoP based parameters.

FIGURE CAPTIONS

Figure 1 – Estimated marginal means and standard error of the phase durations and CoP based parameters under the single- and dual-task conditions for both groups.

490 **TABLES**
491

492 **Table 1**

	Start	End
Phase 1	The instant when the CoP signal derived from the baseline (obtained in the sitting position) was greater than 3 standard deviations for a minimum interval of 50 ms.	The instant associated to the first local maximum of the CoP signal from the sit-to-stand sequence.
Phase 2	The instant associated to the first local maximum of the CoP signal from the sit-to-stand sequence.	The instant of the first local minimum of the CoP signal during the sit-to-stand sequence.
Phase 3	The instant of the first local minimum of the CoP signal during the sit-to-stand sequence.	The instant when the CoP signal values were lower than the baseline (obtained in the standing position) plus 3 standard deviations for a minimum interval of 50 ms.
Phase 4	The instant when the CoP signal derived from the baseline (obtained from the standing position) was greater than 3 standard deviations for a minimum interval of 50 ms.	The instant associated to the first local maximum of the CoP signal from the standing-to-sit sequence.
Phase 5	The instant associated to the first local maximum of the CoP signal from the standing-to-sit sequence.	The instant when the CoP signal values were higher than the baseline (obtained in the siting) plus 3 standard deviations for a minimum interval of 50 ms.

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Table 2

	Individuals with PD (n=9)	Healthy Controls (n=9)	p-value
	M ± SD	M ± SD	
Age [years]	66.00 ± 8.22	63.89 ± 8.09	0.340*
Gender (male), n (%)	6 (66.7)	4 (44.4)	0.319**
Education [years]	7.67 ± 5.07	7.78 ± 4.58	0.796*
Weight [Kg]	69.33 ± 12.59	74.00 ± 9.86	0.796*
Height [m]	1.65 ± 0.08	1.64 ± 0.08	0.931*
MoCA	24.44 ± 2.24	26.33 ± 1.00	0.063*
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 ± 5.38	-	-
Stroop test (Nº of naming colours)	30.89 ± 11.19	35.611 ± 17.099	0.489*

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.

Table 3

		Covariates adjusted - p-values				
Phase		Duration	CoPAP	CoPML	VelAP	VelML
	Group (between-subject)	0.267	0.276	0.725	0.662	0.909
1	Group (within-subjects)	0.348	0.640	0.817	0.765	0.943
	Interaction	0.712	0.210	0.145	0.513	0.959
	Group (between-subject)	<0.05	0.088	0.606	0.238	0.496
2	Group (within-subjects)	0.149	0.623	0.787	0.408	0.986
	Interaction	0.092	0.120	0.167	0.737	0.932
	Group (between-subject)	<0.01	<0.05	0.449	0.062	0.054
3	Group (within-subjects)	0.354	0.271	0.625	0.885	0.150
	Interaction	0.606	0.137	0.410	0.614	0.089
	Group (between-subject)	<0.01	0.056	<0.05	<0.01	0.844
4	Group (within-subjects)	<0.01	0.740	0.325	0.822	0.071
	Interaction	0.333	0.499	0.069	0.493	0.108
	Group (between-subject)	0.173	<0.05	0.734	0.077	0.590
5	Group (within-subjects)	0.587	<0.05	0.074	<0.01	0.284
	Interaction	<0.05	0.369	0.125	<0.01	0.795

FIGURES

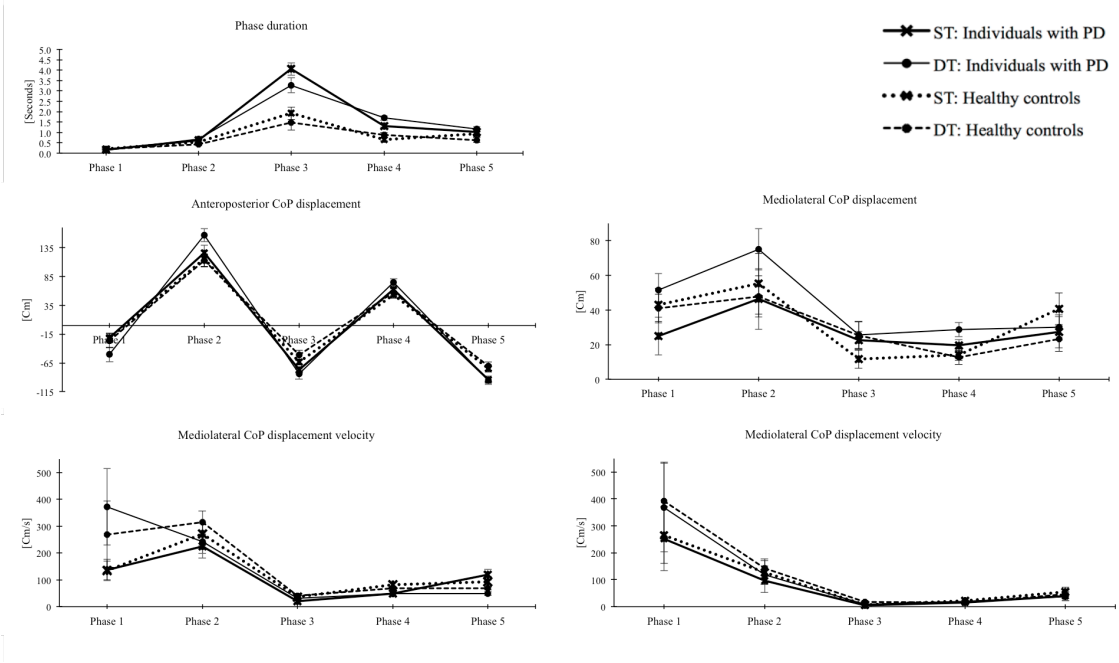

Figure 2