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RESEARCH ARTICLE

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Relationship Between Posturography, Clinical Balance and Executive Function in Parkinsońs Disease

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ABSTRACT. This study aimed to evaluate the relationship between posturography, clinical balance, and executive function tests in Parkinsońs disease (PD). Seventy-one people participated in the study. Static posturography evaluated the center of pressure fluctuations in quiet standing and dynamic posturography assessed sit-to-stand, tandem walk, and step over an obstacle. Functional balance was evaluated by Berg Balance Scale, MiniBESTest, and Timed Up and Go test. Executive function was assessed by Trail Making Test (TMT) and semantic verbal fluency test. Step over obstacle measures (percentage of body weight transfer and movement time) were moderately correlated to Timed Up and Go, part B of TMT and semantic verbal fluency ($r > 0.40$; $p < 0.05$ in all relationships). Stepping over an obstacle assesses the responses to internal perturbations. Participants with shorter movement times and higher percentage of body weight transfer (higher lift up index) on this task were also faster in Timed Up and Go, part B of TMT, and semantic verbal fluency. All these tasks require executive function (problem solving, sequencing, shifting attention), which is affected by PD and contribute to postural assessment.

Keywords: Parkinson's disease, balance, postural control, cognition

Introduction

Postural instability and falls increase the morbidity and mortality in people with Parkinson's disease (PD) (Williams, Watt, & Lees, 2006). The early recognition and treatment of balance impairments can minimize motor complications related to PD (Morris et al., 2011). Postural control mechanisms can be evaluated using static and dynamic posturography, which have experimental and clinical relevance (Ebersbach & Gunkel, 2011; Ganesan, Pal, Gupta, & Sathyapraabha, 2010; Ickenstein et al., 2012; Valkovic, Abrahámová, Hlavacka, & Benetin, 2009). Static posturography evaluates body sway during quiet standing. It quantifies the center of pressure (COP) fluctuations during several conditions, e.g. with open and closed eyes (Ickenstein et al., 2012; Valkovic et al., 2009). Dynamic posturography evaluates postural control in response to internal and/or external perturbations (Blaszczyk & Orawiec, 2011; Ebersbach & Gunkel, 2011; Oude Nijhuis, Allum, Nanhoe-Mahabier, & Bloem, 2014).

Some studies evaluated motor responses after external perturbations, e.g. maintaining balance while standing on unstable surfaces (Ferrazzoli et al., 2015; Gera, Freeman, Blackinton, Horak, & Kin, 2016; Lee et al., 2012; Oude Nijhuis et al., 2014). Other protocols explored the limits of stability, e.g. moving the pelvis and trunk in specific directions to disturb the COP while keeping the same position of feet (Dona et al., 2016; Ganesan et al., 2010; Johnson et al., 2013; Rossi-Izquierdo et al., 2014). However, little is known about other dynamic posturography measures that reflect anticipatory postural adjustments in self-initiated and sequential movements (sit-to-stand, tandem walk and step over an obstacle). When a voluntary movement coexists with equilibrium maintenance against gravity, feedforward adjustments of postural muscles are used to counteract the expected perturbing forces. These reactions are generated in anticipation of a perturbation, and they are called anticipatory postural adjustments (Aruin&Latash, 1995). Anticipatory postural adjustments, e.g. standing from a chair or stepping over an obstacle, are disrupted in people with PD (Oude Nijhuis et al., 2014).

The most commonly used clinical tests to assess functional mobility and postural instability in people with PD are the Berg Balance Scale (BBS) (Scalzo et al., 2009), the MiniBESTest (Leddy, Crowner, & Earhart, 2011b), and the Timed Up and Go Test (Herman, Weiss, Brozgol, Giladi, & Hausdorff, 2014; Vance, Healy, Galvin, & French, 2015). Tests combining different aspects of mobility (such as walking, turning, sit-to-stand, and gait initiation) have been shown to be moderately accurate in predicting falls in individuals with PD (Herman et al., 2014; Kerr et al., 2013; Vance et al., 2015). The tasks assessed by BBS, MiniBESTest, and Timed Up and Go involve not only anticipatory postural control, but also motor planning and sequencing, attention and executive function (Souza, Voos, Francato, Chien, & Barbosa, 2013; Varalta et al., 2015). People with better motor planning/sequencing and better

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cognitive function have lower falls risk (Gago et al., 2009; Higginson, Lanni, Sigvardt, & Disbrow, 2013).

Although the relationships between clinical motor and executive function tests in people with PD are well established in the literature, the relationships between posturography and executive function have been poorly explored. Executive function deficits can significantly affect functional independence and increase falls risk in PD (Higginson et al., 2013). Executive function involves the ability to process internal and external information, perform multiple tasks concurrently, achieve goals, solve problems, and regulate environmental demands. As PD progresses, executive function and postural control deteriorate and the degree of cognitive-motor negative interference increases (Lee et al., 2012; Mak, Wong, & Pang, 2014; Smulders et al., 2013). Cognitive-motor negative interference means that the association of a cognitive and a motor tasks disrupts the performance of one of both tasks (Barbosa et al., 2016). The Trail Making Test (TMT) has been used to evaluate executive function in people with PD. Part B of TMT can be used to assess mental flexibility and working memory and it is considered an accurate measure of executive function (Bowie & Harvey, 2006; Tombaugh, 2004; Zalonis et al., 2008). Poor executive function, detected by TMT, is related to poor daily functioning, gait and balance in older adults and in people with PD (Ble et al., 2005; Gago et al., 2009; Higginson et al., 2013).

Verbal fluency tests can also be considered a measure of executive function, because they require central processing organization of verbal retrieval and recall, self-monitoring, self-initiation, and inhibition of responses (Varalta et al., 2015). Deficits on semantic fluency are more frequently reported than deficits on phonemic fluency. Verbal fluency performance was correlated with UPDRS and Timed up and Go (Henry & Crawford, 2004). Most people with PD have difficulty walking and talking simultaneously and stop walking when talking. Therefore, verbal fluency and its correlation with postural control must be better explored.

Barbosa et al. (2015) investigated the impact of dual-task performance (on a verbal fluency task while keeping balance in standing) in people with PD and healthy controls. Static posturography showed that people with PD had higher body sway than controls in all evaluations (quiet stance and dual-task). Balance on dual-task with eyes closed (EC) was significantly poorer (higher body sway) than with eyes open (EO). Static posturography was weakly correlated to clinical balance scales. However, neuropsychological scores were correlated with postural control (evaluated by static and dynamic posturography) in people in the early stages of PD (Hoehn & Yahr stages 1–2; stage 1: unilateral effects; stage 2: bilateral effects without balance impairment) (Lee et al., 2012).

To our knowledge, no previous studies investigated the correlations between quiet stance control (mediolateral and anteroposterior body sway amplitude, velocity, and area), dynamic postural control (sit-to-stand, tandem walk and step over an obstacle), clinical balance tests (BBS, MiniBESTest and Timed Up and Go), and executive function tests (TMT and semantic verbal fluency). Considering that clinical balance tests involve mainly dynamic anticipatory postural adjustments, we hypothesized that sit-to-stand, tandem walk, and step over an obstacle would show higher correlations with clinical balance and executive function tests than static posturography measures in people with PD. This information can help optimizing clinical decision making and research protocols. The objective of this study was to investigate the relationships between quiet stance control, and dynamic postural control, clinical balance, and executive function tests.

Method

Participants

A total of 90 patients with confirmed idiopathic PD from the Movement Disorders Clinic, Department of Neurology, Clinics Hospital, University of São Paulo, were recruited. Seventy-one met the inclusion and exclusion criteria. Inclusion criteria included being diagnosed with PD according to the clinical diagnostic criteria of the United Kingdom Parkinson's Disease Society Brain Bank (Daniel & Lees, 1993), having Hoehn & Yahr scale score between 2 and 3 (Hoehn & Yahr, 1967), and having self-reported antiparkinsonian drugs treatment regimen at a stable and optimized daily dose for at least four weeks prior to joining the study (Stocchi, Jenner, & Obeso, 2010). All testing procedures took place while patients were on medication. Participants were tested between 40 minutes and 1 hour after the latest levodopa intake.

Potential participants were excluded from the study if they had moderate or severe chronic obstructive pulmonary disease, uncontrolled hypertension, myocardial infarction in the past six months, uncontrolled metabolic disease, acute orthopedic injury, other neurologic diseases, depression, cognitive impairment (determined by the Brazilian version of the Mini-Mental State Examination; Brucki, Nitrini, Caramelli, Bertolucci, & Okamoto, 2003) and vision impairment (detected by the Snellen chart; Kalinowski, 2008). Individuals wearing proper corrective lenses were not excluded. The study protocol was approved by the ethics committee at University of São Paulo. Participants received information about the study and signed the written informed consent prior to participating.

Posturography Measures

Quiet Stance Control

Static balance assessments were performed using a mobile force platform (AMTI AccuSway^{Plus} Balance Platform, Advanced Mechanical Technology Inc., USA). All ground reaction forces and moments were recorded by transducers on the force platform in the mediolateral, anteroposterior, and vertical directions at a 100 Hz sampling frequency using a 12-bit data acquisition system. COP fluctuations were calculated and stored using AMTIBalance

Clinicsoftware® (Advanced Mechanical Technology Inc., USA). A low-pass, fourth order, Butterworth filter with a 10 Hz cutoff frequency was applied (Schmid, Conforto, Camomilla, Cappozzo, &D'Alessio, 2002).

During the tests, participants were asked to stand upright without shoes, with both feet on the platform, and with comfortable position (Blaszczyk & Orawiec, 2011). Feet position was marked on a sheet of paper that was attached to the force platform. Four points were marked for each foot, including the hallux, the head of the fifth metatarsal, the lateral malleolus, and the medial malleolus. Foot position was the same during static posturography procedures. Participants were instructed to stand quietly, keep their arms along the sides of the body, and not move. Participants were also asked to keep their eyesight fixed on a point positioned one meter in front of them, which was 10 cm lower than their height. Three, 60 second-trials were recorded with the EO, and three with the EC. At the beginning of each trial, a verbal command was given indicating the beginning of the test. Data recording started five seconds after, so that the initial sway was discarded. After each trial, the platform was reset for the next test.

COP fluctuations in the anteroposterior and mediolateral directions were automatically computed using the AMTIBalance Clinicsoftware (Duarte & Freitas, 2010). The parameters were (1) standard deviations of COP displacement (cm), calculated to describe the amount of sway in anteroposterior and mediolateral directions (cm); (2) mean velocity of COP fluctuations (cm/s), calculated by dividing the total COP displacement in all directions by the time; and (3) elliptical area of 95% of displacement, calculated in a way that 95% of all the COP fluctuations fit inside the area (Duarte & Freitas, 2010). The mean values from the three trials were computed for each measure for the EO and EC conditions.

Dynamic Postural Control

Dynamic balance assessments were performed using the Balance Master system (version 8.1, Neurocom International, USA). Performances on: (1) sit-to-stand, (2) tandem walk, and (3) step over obstacle were assessed. All signals were recorded at a 20 Hz sampling frequency.

During sit-to-stand, participants were seated on a wooden box and instructed to push against the platform with both feet, stand up and keep on the standing posture for five seconds. Weight transfer is the time (in seconds) required to perform the transfer from sitting to standing. The inability to move the center of gravity forwards disrupts this transfer process. The rising index is the amount of force exerted by the legs during the rising phase (from sitting to standing), expressed as a percentage of body weight (Luque-Siles et al., 2016). Any insufficient force can result in a failure to rise (but this did not happen in the present study). Higher scores mean that the participant can transfer the center of gravity forwards to a new base of support. Three trials of each task were performed, and the means of weight transfer and rising index was calculated.

During tandem walking, participants were asked to walk as quickly as possible, along the force platform. They were instructed to try to touch toes of the back foot to the heel of the front foot in each step. Tandem mediolateral stability and speed were automatically measured by the Balance Master System. Tandem mediolateral stability (expressed in centimeters) is inferred by the mean distance between the center of gravity and the reference path. Participants able to maintain this narrow base of support are considered to have good balance and postural control (Oshita & Yano, 2017). Participants with postural instability compensate by increasing steps width, because larger base of support provides stability. Tandem speed is the mean velocity of forward progression in tandem (cm/second). During the task, participants were encouraged to walk as quickly as possible. Three trials were performed and the mean was calculated.

In stepping over obstacle, participants were instructed to step on a 10-centimeter wooden box with one foot, swing the other leg over the box and maintain both legs as steady as possible on the platform, for five seconds. All participants started stepping with the non-dominant leg. The lift-up index is automatically registered by the Balance Master System and quantifies the maximal lifting force exerted by the leg stepping on the obstacle, represented as a percentage of body weight. Three trials were performed and the mean was used as the lift-up index of the non-dominant and the dominant leg. Lower indexes indicate that force was not enough to move the body over the object. The mean lift up index in older adults is about 47% with a standard deviation of 14% (NeuroCom International Inc. Balance MasterSystem operator's manual, 2003). During the step-over task, the movement time (in seconds) required to perform the task was registered. Participants with better postural control were reported to perform the task faster (Nocera et al., 2010; Park, Ko, & Park, 2013).

Sit-to-stand, tandem walk, and step over obstacle were chosen to assess dynamic postural control because they simulate activities of daily living: standing from a chair, keeping balance while walking in narrow spaces, trespassing obstacles, and climbing steps. People with PD usually report difficulty in these tasks (reduced speed, need for assistance or support, falls) (Oude Nijhuis et al., 2014).

Clinical Tests

Clinical Balance Tests

The BBS is an ordinal reliable and valid test (Leddy, Crowner, & Earhart, 2011a; Miyamoto, Lombardi Junior, Berg, Ramos, & Natour, 2004; Scalzo et al., 2009). It measures the ability to maintain balance during functional tasks. Participants are asked to maintain sitting balance, transfer from one chair to another, rise from a chair, stand, reach for an object, and turn around when standing. Each task is scored from 0 to 4 and the sum of the scores is added to obtain the total score (from 0 to 56).

The MiniBESTest is a reliable battery of balance and mobility tasks. It evaluates anticipatory control (total score 0–6, tasks: sit to stand, rise to toes, stand on one leg), reactive postural control (total score 0–6, tasks: compensatory stepping forward, backward and lateral), sensory orientation (total score 0–6, tasks: standing with eyes open/ firm surface and eyes closed/ foam surface, standing on a ramp), and dynamic gait (total score 0–10, tasks: changing gait speed, turning the head, pivot turns, stepping over obstacles, counting backwards) (Leddy et al., 2011a).

The Timed Up and Go Test is a reliable and valid mobility assessment tool, which has sensitivity and specificity for identifying falls risk in People with PD (Vance et al., 2015). Participants must rise from sitting on an armchair, walk for three meters, turn around, walk back, and sit down again. The total time (in seconds) is measured with a stopwatch.

Executive Function Tests

The TMT is a measure of executive function, with well-established normative data. Performance is usually impaired in People with PD, even in cases with no dementia symptoms (Biundo et al., 2014; Ranchet, Broussolle, Poisson, & Paire-Ficout, 2012). TMT can detect individuals who have difficulties performing activities of daily living (Bowie & Harvey, 2006; Zalonis et al., 2008), because it involves mental flexibility, spatial attention, and working memory (Tombaugh, 2004). In part A, participants are asked to connect numbers from 1 to 25. In part B, participants must connect randomly positioned numbers (1 to 12) and letters (A to M) in an alternating number-letter sequence (i.e., 1-A-2-B-3-C etc). The time (in seconds) taken to complete the trail is registered (Bowie & Harvey, 2006). Based on these scores, delta TMT (part B – part A) and ratio TMT (part B/part A) were calculated (Sanchez-Cubillo et al., 2009).

The semantic verbal fluency test assesses memory, executive function, and phonoarticulatory control. Participants are instructed to say as many animals as they could remember in one minute, without repeating or gender changing. Each new word is scored with one point; repeated words are not scored (Brucki & Rocha, 2004). This test is a predictor of dementia and it can distinguish between cognitively impaired from non-impaired patients (Herrera, Cuetos, & Ribacoba, 2012). Henry and Crawford (2004) found that semantic fluency deficits were frequently observed in people with PD.

TMT and verbal fluency are influenced by the number of years of formal education (Bott et al., 2014; Bowie & Harvey, 2006; Zalonis et al., 2008). Education was evaluated by self-report about the total number of years of formal education (“How many years have you been in school?”)

Statistical Analysis

Shapiro–Wilk test showed that data was normally distributed. Pearson correlation coefficients were calculated to quantify the relationships betweenquiet stance control, dynamic postural control and clinical balance/executive function tests. Correlations were corrected by duration of disease and by number of years of formal education. Significance level was set at alpha < 0.05.

Results

Static Posturography and Clinical Tests

Table 1 shows the means, standard deviations (SD) and ranges of demographic and clinical data (Table 1).

No significant correlations between static posturography, clinical balance, and executive function were found.

Dynamic Posturography and Clinical Tests

Sit-to-stand and tandem walk did not significantly correlate to clinical balance and executive function tests. Pearson correlation coefficients between step over task and clinical tests are shown in Table 2. Partial correlations were corrected by disease duration and by education. Timed Up and Go, part B of TMT, and semantic verbal fluency moderately correlated to step over obstacle (Table 2). Figures 1 and 2 show the correlations between stepping over an obstacle (movement time and lift up index), Timed Up and Go test and semantic verbal fluency test (Figures 1 and 2).

Discussion

The present study investigated the relationship between posturography and clinical (balance and executive function) tests. The results showed that step over obstacle measures (percentage of body weight transfer and movement time) were moderately correlated to the Timed Up and Go, part B of TMT, and semantic verbal fluency.

Posturography and Clinical Balance

In the present study, the scores on clinical balance tests were correlated to dynamic postural control, but not to quiet stance control measures. Previously, Johnson et al. (2013) tested the efficacy of clinical tests and static and dynamic posturography to discriminate between fallers and non-fallers with PD (Hoehn & Yahr scale scores 1–3) and healthy controls. They found that BBS and Timed Up and Go tests were closely correlated with the history of falling. The amount of postural sway (path length and sway area) during static posturography discriminated between fallers with PD and controls but not between fallers and non-fallers with PD. However, dynamic posturography (reaction time and velocity) discriminated between fallers and non-fallers with

TABLE 1. Demographic and clinical characteristics: mean, standard deviation (SD), and range (min – max)

Variables	Mean	SD	Range (min – max)
Age (years)	63.4	6.7	50–75
Sex			
Female	19 (27%)	—	—
Male	52 (73%)		
Duration of PD (years)	8.7	5.7	2–30
Education	8.6	4.3	3–17
Hoehn and Yahr (stage)	2.5	0.3	2–3
UPDRS motor section (score)	28.3	10.8	6–54
Berg Balance Scale (score)	51.7	4.2	37–56
Timed Up and Go Test (s)	8.5	2.5	5–23
MiniBESTest (score)	24.3	4.4	12–31
Trail Making Test part A (s)	72.8	58.9	17–292
Trail Making Test part B (s)	174.5	91.7	36–300
Semantic Verbal Fluency (words)	12.8	4.7	1–25

PD, as well as between PD and control groups. They showed correlations between static and dynamic posturography measures and BBS and Timed Up and Go test. In the present study, we observed complementary findings: dynamic postural control tasks showed higher correlation coefficients with clinical balance scores than with quiet stance control measures. Clinical balance tests involve mainly dynamic anticipatory postural adjustments, which explains our findings.

We found high correlation coefficients between the Timed Up and Go and stepping over an obstacle. Both tasks require postural corrections to internal perturbations (anticipatory control), motor planning, and sequencing. A relationship between another clinical scale (UPDRS) and dynamic posturography measures (amplitude of dorsiflexion torque to keep balance after platform rotational movements) was also found by Oude Nijhuis et al. (2014).

Although BBS and dynamic postural control (evaluated by the Balance Master System) may have some similarities, some differences can explain the absence of correlations between their scores (Lee et al., 2012). Tandem assessment in BBS was based on maintaining the tandem static position. Opposite, in the Balance Master System assessment, the dynamic performance of successive steps was scored. During stepping over obstacle, the participant had to memorize and perform a motor sequence: stepping on the box

TABLE 2. Partial correlations corrected by disease duration and education. Correlation coefficients between step over task (dynamic posturography) and clinical balance and cognition tests.

	Partial correlations corrected by disease duration				Partial correlations corrected by education			
	Step over an obstacle task Dynamic posturography				Step over an obstacle task Dynamic posturography			
	Lift up left (%)	Lift up right (%)	Movement time left (sec)	Movement time right (sec)	Lift up left (%)	Lift up right (%)	Movement time left (sec)	Movement time right (sec)
Berg Balance Scale (score)	0.256	0.124	−0.296	−0.141	0.137	0.131	−0.007	−0.036
MiniBESTest (score)	0.329	0.121	−0.370	−0.189	0.298	0.161	−0.133	−0.064
Timed Up and Go test (s)	**−0.432***	**−0.501***	**0.507***	**0.503***	**−0.463***	**−0.511***	**0.443***	**0.452***
Trail Making Test: part A (s)	−0.227	−0.005	0.350	0.182	−0.152	0.011	0.204	0.095
Trail Making Test: part B (s)	−0.199	−0.088	**0.408***	0.373	−0.132	−0.108	**0.401***	0.346
Trail Making Test: B-A	0.036	−0.029	−0.057	−0.045	0.072	−0.028	−0.135	−0.029
Trail Making Test: B/A	−0.091	−0.110	0.206	0.090	−0.015	−0.125	0.063	0.077
Verbal fluency (words)	0.393	0.386	**−0.509***	**−0.441***	0.374	0.354	**−0.426***	**−0.413***

Note. *$r > 0.40$ (moderate correlation); $p < 0.05$. Lift up left and right (%): the maximal lifting force exerted by the leg stepping on the obstacle, represented as a percentage of body weight. Movement time left and right (sec): movement time (in seconds) required to step on a 10-centimeter wooden box with one foot, swing the other leg over the box and maintain both legs as steady as possible on the platform, after trespassing the obstacle, for five seconds.

with one foot, stepping over the box with the other foot, and then keeping both feet together after trespassing the obstacle. In BBS, the task was simpler, and participants had to alternate steps from the ground to a platform.

Our study was the first to investigate correlations between ecological dynamic measures, including the internal perturbations caused by sit-to-stand (weight transfer and rising index), tandem walk (mediolateral stability and speed), and step over obstacle (lift up index and movement time). A combination of clinical and posturographic measures is useful to evaluate people with PD. The posturographic evaluation of open-loop tasks involving dynamic postural control can provide information to help therapists develop treatment strategies, e.g. on sit-to-stand: Can the patient transfer weight forwards? Can the patient raise the pelvis from the bench? Can the patient extend hips and get to standing? As the Balance Master provides quantitative information, it is possible to compare patients to normative values and pre- to post- treatment conditions. In early stages of PD, BBS, and Timed Up and Go can show ceiling effects, as balance is less compromised. The assessment of dynamic postural control can provide a more detailed assessment and detect subtle changes due to aging or pathological processes (Lin, Barker, Sparto, Furman, & Huppert, 2017; Rossi-Izquierdo et al., 2014; Visser et al., 2010).

Posturography and Executive Function

We observed correlations between step over obstacle and executive function. Recent studies showed that postural instability in PD is associated to poorer performance on attention and executive function tests, and that fallers usually perform worse on attention tests than non-fallers (Nocera et al., 2010; Rossi, Soto, Santos, Sesar, & Labella, 2009). Surprisingly, part B of TMT showed higher correlations to step over obstacle than the ratio and the delta of TMT scores. Both tasks are not purely cognitive (as ratio and delta), they are cognitive-motor tasks that involve motor planning and sequencing.

Step over obstacle assesses the postural responses to internal perturbations during trespassing a step. Participants with shorter movement times and more efficient anticipatory postural adjustments on this task were also faster in the Timed Up and Go, part B of TMT and semantic verbal fluency (Barbosa et al., 2016; Barbosa et al., 2015). These tasks require executive function (problem solving, sequencing, shifting attention, etc.), which is affected by PD. They also identify impaired motor sequence components (e.g. weight transfer difficulty) and detect people at risk of falling.

Kunikowska et al. (2014)analyzed postural instability (static posturography) and cognition (Mini Mental State Examination and counting backwards) in people with PD and healthy individuals. PD was associated to lower scores on Mini Mental State Examination and longer duration of counting backwards responses. People with PD showed significant delay in counting backwards (Kunikowska et al., 2014). Our study showed that other tests involving executive function, such as TMT and semantic verbal fluency, were correlated to postural control. The correlation between dynamic postural control and executive function may be explained by the fact that both require problem solving and motor sequencing (Barbosa et al., 2016). Executive function and postural control performance can be affected by cognitive-motor negative interference (Lee et al., 2012; Mak et al., 2014; Smulders et al., 2013). Poor executive function was related to gait and balance impairments in people with PD (Gago et al., 2009; Higginson et al., 2013).

The association between postural instability and poor executive function in PD was shown by Mak et al. (2014). They concluded that impaired executive function was a significant predictor of falls in people with PD in a 12-

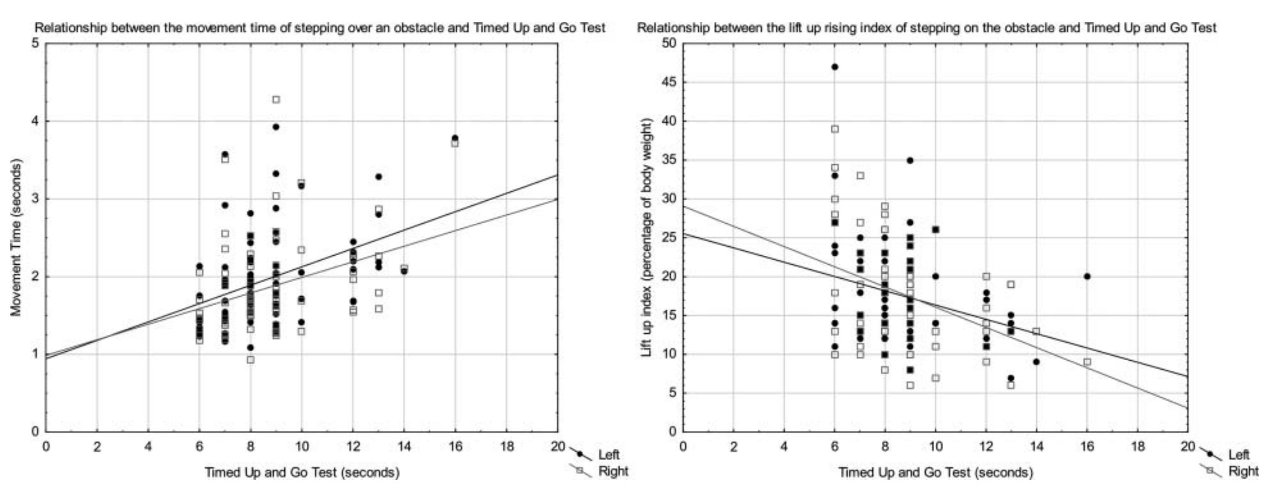

FIGURE 1. Correlations between stepping over an obstacle (movement time and lift up index) and Timed Up and Go test.

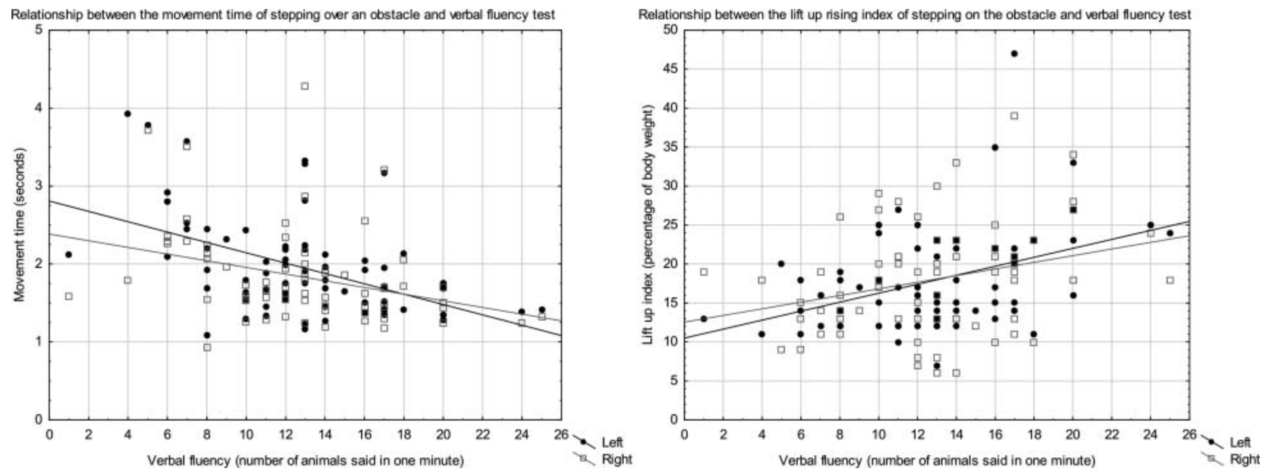

FIGURE 2. Correlations between stepping over an obstacle (movement time and lift up index) and semantic verbal fluency test.

month follow-up. Additionally, postural instability and gait disturbances were more prevalent in people with PD who suffered from dementia (Lyros, Messinis, & Papathanasopoulos, 2008; Rossi et al., 2009). Therefore, executive function and postural control have been consistently related (Souza et al., 2013).

The semantic verbal fluency, which is also a measure of executive function, was correlated with other functional mobility measures by Varalta et al. (2015). They compared the semantic verbal fluency with functional balance and mobility tasks, as BBS, Timed Up and Go, and UPDRS. They found correlations between the number of words in semantic verbal fluency and the time on Timed Up and Go. No previous studies investigated the relationship between dynamic postural control and semantic verbal fluency. The scores on verbal fluency correlated to lift up index and movement time of step over obstacle. This task is more complex than the other two dynamic tasks (rise from a bench and tandem walk). It demands more sequential movements and, consequently more postural adjustments, with less support, which increases the amount of central processing. McDowd et al. (2011) showed that the speed of central processing is critical in the verbal fluency test, which explains our findings. Both verbal fluency and balance require automatic control, which is impaired by PD (Barbosa et al., 2015; Błaszczyk & Orawiec, 2011; Ickenstein et al., 2012).

Lee et al. (2012) investigated the relationships between dynamic posturography measures and cognitive impairment in early stages of PD. They found relationships between postural instability (sensory organization test and backward platform translation) and cognitive function (neuropsychological battery). Our findings are consistent with the study by Lee et al. (2012) and show that body sway control and cognition are correlated. The present study shows that other dynamic tasks (weight transfer/rising index of sit-to-stand, mediolateral stability/speed of tandem walk and lift up index/movement time of step over obstacle) are correlated to clinical balance and executive function in people with PD (Hoehn and Yahr 2–3). In a study by Lee et al. (2012), dynamic posturography was based on sensory open-loop perturbations (visual, vestibular, and proprioceptive). The present study showed that self-initiated and regulated closed loop tasks are also correlated to executive function in PD.

The cholinergic system may play a pivotal role as a unifying factor in balance and cognition control. The nucleus basalis of Meynert supplies most cholinergic inputs to the cerebral cortex, modulating the hippocampus activity and cognitive frontoparietal networks (Coyle, Price, & DeLong, 1983). Moreover, the cholinergic pedunculopontine nucleus exerts a key role on both posture and attention (Mena-Segovia, Bolam, & Magill, 2004). A neuroimaging study (Rochester et al., 2012) used the short-latency afferent inhibition method to reflect cholinergic activity. It demonstrated the association between gait dysfunction, cholinergic deficiency, and attention impairment in people with PD.

As a limitation, we must mention that this study is cross-sectional. Future studies should investigate whether the relationships between posturography, clinical balance, and executive function are modified as PD progresses. In conclusion, posturography is a useful tool for the complementary evaluation of balance in PD. It is important to evaluate people with PD with both posturography and clinical tests to accurately describe their balance.

CONCLUSIONS

Dynamic, but not static postural control was correlated to clinical balance and executive function tests. Therefore, dynamic postural control tasks, evaluated by posturography, can be a useful complementary tool for evaluating balance impairment. Taken together, posturography, clinical balance, and executive function tests provide insights about motor control and therapies for people with PD.

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