

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/324713145>

# Relationship Between Posturography, Clinical Balance and Executive Function in Parkinson's Disease

Article in *Journal of Motor Behavior* · April 2018

DOI: 10.1080/00222895.2018.1458279

CITATIONS

2

READS

280

10 authors, including:



**Carolina de Oliveira Souza**  
University of São Paulo

21 PUBLICATIONS 98 CITATIONS

[SEE PROFILE](#)



**Mariana Callil Voos**  
University of São Paulo

102 PUBLICATIONS 223 CITATIONS

[SEE PROFILE](#)



**Alessandra Barbosa**

13 PUBLICATIONS 28 CITATIONS

[SEE PROFILE](#)



**Matija Milosevic**  
Osaka University

39 PUBLICATIONS 140 CITATIONS

[SEE PROFILE](#)

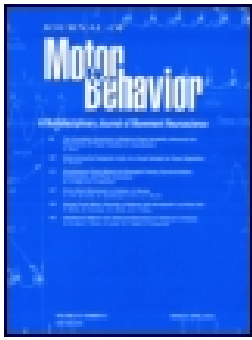
Some of the authors of this publication are also working on these related projects:



Pain and Parkinson Disease [View project](#)



Functional evaluation scale for Duchenne muscular dystrophy (FES-DMD) [View project](#)



## Relationship Between Posturography, Clinical Balance and Executive Function in Parkinson´s Disease

Carolina de Oliveira Souza, Mariana Callil Voos, Alessandra Ferreira Barbosa , Janini Chen, Debora Cristina Valente Francato, Matija Milosevic, Milos Popovic, Erich Talamoni Fonoff, Hsin Fen Chien & Egberto Reis Barbosa

To cite this article: Carolina de Oliveira Souza, Mariana Callil Voos, Alessandra Ferreira Barbosa , Janini Chen, Debora Cristina Valente Francato, Matija Milosevic, Milos Popovic, Erich Talamoni Fonoff, Hsin Fen Chien & Egberto Reis Barbosa (2018): Relationship Between Posturography, Clinical Balance and Executive Function in Parkinson´s Disease, Journal of Motor Behavior, DOI: [10.1080/00222895.2018.1458279](https://doi.org/10.1080/00222895.2018.1458279)

To link to this article: <https://doi.org/10.1080/00222895.2018.1458279>



Published online: 23 Apr 2018.



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



Article views: 20



View related articles [↗](#)



View Crossmark data [↗](#)



## RESEARCH ARTICLE

# Relationship Between Posturography, Clinical Balance and Executive Function in Parkinson's Disease

Carolina de Oliveira Souza<sup>1,2,3</sup>, Mariana Callil Voos<sup>3,4</sup>, Alessandra Ferreira Barbosa<sup>3,4</sup>,  
Janini Chen<sup>1,3</sup>, Debora Cristina Valente Francato<sup>1</sup>, Matija Milosevic<sup>5,6</sup>, Milos Popovic<sup>5,6</sup>,  
Erich Talamoni Fonoff<sup>2</sup>, Hsin Fen Chien<sup>1,3</sup>, Egberto Reis Barbosa<sup>1</sup>

<sup>1</sup>Movement Disorders Clinic, Department of Neurology, Clinics Hospital of University of São Paulo, School of Medicine, São Paulo, Brazil. <sup>2</sup>Department of Functional Neurosurgery, Clinics Hospital of University of São Paulo, School of Medicine, São Paulo, Brazil. <sup>3</sup>ReMove, Rehabilitation in Movement Disorders Research Group, São Paulo, SP, Brazil. <sup>4</sup>Physical Therapy, Occupational Therapy and Speech Therapy Department, University of São Paulo, School of Medicine, São Paulo, Brazil. <sup>5</sup>Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, Ontario, Canada. <sup>6</sup>Rehabilitation Engineering Laboratory, Lyndhurst Centre, Toronto Rehabilitation Institute – University Health Network, Toronto, Ontario, Canada.

**ABSTRACT.** This study aimed to evaluate the relationship between posturography, clinical balance, and executive function tests in Parkinson's 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, & Sathyaprabha, 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 (Arui&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, Crouner, & 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

---

Correspondence address: Mariana CallilVoos, Universidade de São Paulo. R Cipotânea, 51, 2º andar, 05360-000 Cidade Universitária São Paulo, SP, Brazil. e-mail: fmarivoos@gmail.com

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<sup>Plus</sup> 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 (Błaszczyk & 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, Crouner, & 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 between quiet 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				Step over an obstacle task			
	Dynamic posturography				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)	<b>–0.432*</b>	<b>–0.501*</b>	<b>0.507*</b>	<b>0.503*</b>	<b>–0.463*</b>	<b>–0.511*</b>	<b>0.443*</b>	<b>0.452*</b>
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	<b>0.408*</b>	0.373	–0.132	–0.108	<b>0.401*</b>	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	<b>–0.509*</b>	<b>–0.441*</b>	0.374	0.354	<b>–0.426*</b>	<b>–0.413*</b>

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, swinging 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**

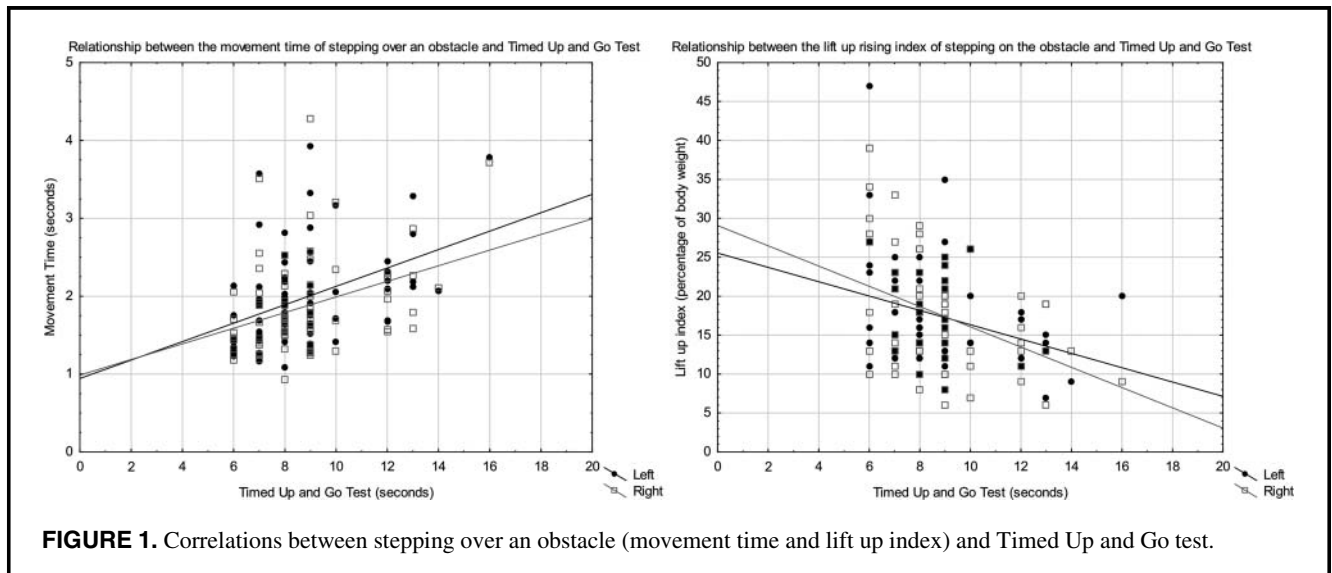
We observed correlations between step over obstacle and executive function. Recent studies showed that postural instability in PD is associated to poorer performance on attention and executive function tests, and that fallers usually perform worse on attention tests than non-fallers (Nocera et al., 2010; 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.

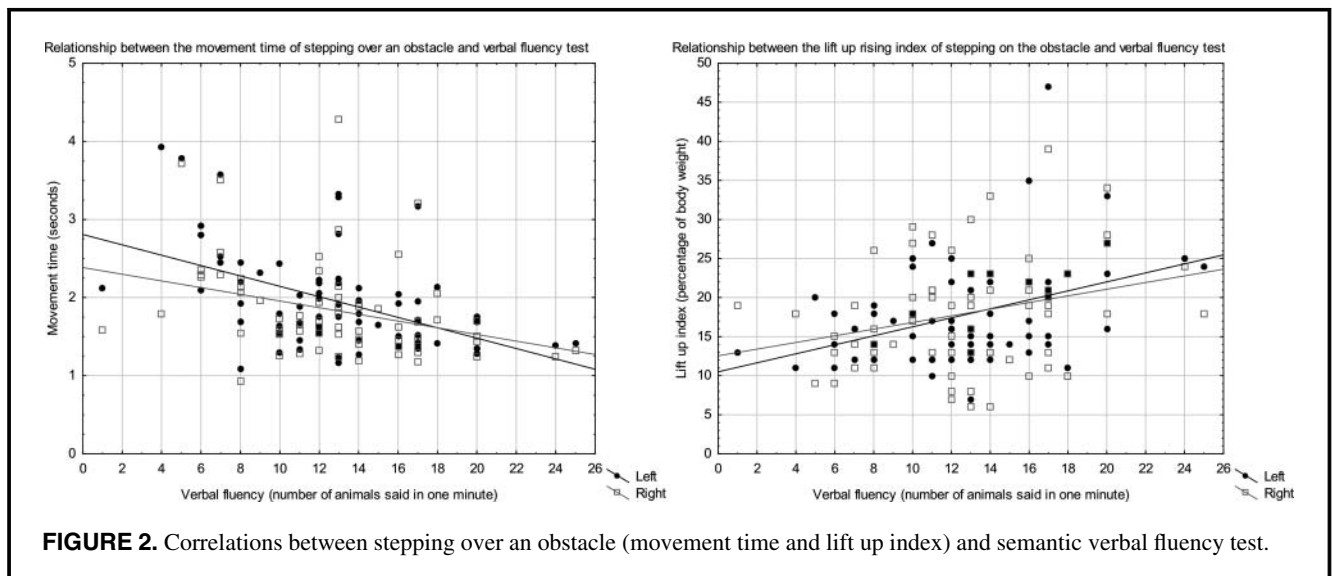
Step over obstacle assesses the postural responses to internal perturbations during trespassing a step. Participants with shorter movement times and more efficient anticipatory postural adjustments on this task were also faster in the Timed Up and Go, part B of TMT and semantic verbal fluency (Barbosa 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-







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; Błaszczuk & 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.


## ORCID


Mariana Callil Voos  <http://orcid.org/0000-0001-6252-7287>

Alessandra Ferreira Barbosa  <http://orcid.org/0000-0002-8215-7858>

Janini Chen  <http://orcid.org/0000-0003-3591-1472>

Debora Cristina Valente Francato  <http://orcid.org/0000-0003-1008-5012>

Matija Milosevic  <http://orcid.org/0000-0001-7629-1850>

Milos Popovic  <http://orcid.org/0000-0002-2837-2346>

Erich Talamoni Fonoff  <http://orcid.org/0000-0001-7831-9941>

## REFERENCES

- Aruin, A., & Latash, M. (1995). The role of motor action in anticipatory postural adjustments studied with self-induced and externally triggered perturbations. *Experimental Brain Research*, *106*, 291–300. doi:10.1007/BF00241125
- Barbosa, A. F., Chen, J., Freitag, F., Francato, D. V., Souza, C. O., Voos, M. C., & Chien, H. F. (2016). Gait, posture and cognition in Parkinson's disease. *Dementia & Neuropsychologia*, *10*(4), 280–286.
- Barbosa, A. F., Souza, C. O., Chen, J., Francato, D. V., Caromano, F. A., Chien, H. F., ... Voos, M. C. (2015). The competition with a concurrent cognitive task affects posturographic measures in patients with Parkinson disease. *Arquivos de Neuro-Psiquiatria*, *73*(11), 906–912.
- Biundo, R., Weis, L., Facchini, S., Formento-Dojot, P., Valletunga, A., Pilleri, M., & Antonini, A. (2014). Cognitive profiling of Parkinson disease patients with mild cognitive impairment and dementia. *Parkinsonism & Related Disorders*, *20*(4), 394–399. doi:10.1016/j.parkreldis.2014.01.009
- Błaszczczyk, J. W., & Orawiec, R. (2011). Assessment of postural control in patients with Parkinson's disease: Sway ratio analysis. *Human Movement Science*, *30*(2), 396–404. doi:10.1016/j.humov.2010.07.017
- Ble, A., Volpato, S., Zuliani, G., Guralnik, J. M., Bansdinelli, S., Lauretani, F. et al. (2005). Executive function correlates with walking speed in older persons: The InCHIANTI study. *Journal of the American Geriatrics Society*, *53*(3), 410–415. doi:10.1111/j.1532-5415.2005.53157.x
- Bott, N. T., Johnson, E. T., Schuff, N., Galifianakis, N., Subas, T., Pollock, J., ... Possin, K. L. (2014). Sensitive measures of executive dysfunction in non-demented Parkinson's disease. *Parkinsonism & Related Disorders*, *20*(12), 1430–1433. doi:10.1016/j.parkreldis.2014.10.007
- Bowie, C. R., & Harvey, P. D. (2006). Administration and interpretation of the trail making test. *Nature Protocols*, *1*(5), 2277–2281. doi:10.1038/nprot.2006.390
- Brucki, S. M., & Rocha, M. S. (2004). Category fluency test: Effects of age, gender and education on total scores, clustering and switching in Brazilian Portuguese-speaking subjects. *Brazilian Journal of Medical and Biological Research*, *37*(12), 1771–1777. doi:10.1590/S0100-879X2004001200002
- Brucki, S. M. D., Nitrini, R., Caramelli, P., Bertolucci, P. H., & Okamoto, I. H. (2003). Suggestions for utilization of the minimal state examination in Brazil. *Arquivos de Neuro-Psiquiatria*, *61*(3B), 777–781.
- Coyle, J. T., Price, D. L., & DeLong, M. R. (1983). Alzheimer's disease: A disorder of cortical cholinergic innervations. *Science*, *219*(4589), 1184–1190. doi:10.1126/science.6338589
- Daniel, S. E., & Lees, A. J. (1993). Parkinson's disease society brain bank, London: Overview and research. *Journal of Neural Transmission Supplementa*, *39*, 165–172.
- Dona, F., Aquino, C. C., Gazzola, J. M., Borges, V., Silva, S. M. C. A., Gananca, F. F., ... Ferraz, H. B. (2016). Changes in postural control in patients with Parkinson's disease: A posturographic study. *Physiotherapy*, *102*, 272–279. doi:10.1016/j.physio.2015.08.009
- Duarte, M., & Freitas, S. M. S. F. (2010). Revision of posturography based on force plate for balance evaluation. *Revista Brasileira de Fisioterapia*, *14*(3), 183–192. doi:10.1590/S1413-35552010000300003
- Ebersbach, G., & Gunkel, M. (2011). Posturography reflects clinical imbalance in Parkinson's disease. *Movement Disorders*, *26*(2), 241–246. doi:10.1002/mds.23189
- Ferrazzoli, D., Fasano, A., Maestri, R., Bera, R., Palamara, G., Ghilardi, M. F., ... Frazzitta, G. (2015). Balance dysfunction in Parkinson's Disease: The role of posturography in developing a rehabilitation program. *Parkinson's Disease*, *2015*, 2015:520128. Epub 2015 Oct 4. 1–10. doi:10.1155/2015/520128
- Gago, M. F., Garrett, M. C., Fonseca, M. R., Rosas, M. J., Simões, M. F., Vieira, S., & Botelho, F. (2009). How do cognitive and axial motor signs correlate in Parkinson's disease? A 6-year prospective study. *Journal of Neurology*, *256*(10), 1655–1662. doi:10.1007/s00415-009-5174-7
- Ganesan, M., Pal, P. K., Gupta, A., & Sathyaprabha, T. N. (2010). Dynamic posturography in evaluation of balance in patients of Parkinson's disease with normal pull test: Concept of a diagonal pull test. *Parkinsonism & Related Disorders*, *16*(9), 595–599. doi:10.1016/j.parkreldis.2010.08.005
- Gera, G., Freeman, D. L., Blackinton, M. T., Horak, F. B., & Kin, L. (2016). Identification of balance deficits in people with Parkinson disease; is the sensory organization test enough? *International Journal of Physical Medicine & Rehabilitation*, *4*(1), 1–9.
- Henry, J. D., & Crawford, J. (2004). Verbal fluency deficits in Parkinson's disease: A meta-analysis. *Journal of the International Neuropsychological Society*, *10*, 608–622. doi:10.1017/S1355617704104141
- Herman, T., Weiss, A., Brozgol, M., Giladi, N., & Hausdorff, J. M. (2014). Identifying axial and cognitive correlates in patients with Parkinson's disease motor subtype using the instrumented Timed Up and Go. *Experimental Brain Research*, *232*(2), 713–721. doi:10.1007/s00221-013-3778-8
- Herrera, E., Cuetos, F., & Ribacoba, R. (2012). Verbal fluency in Parkinson's disease patients on/off dopamine medication. *Neuropsychologia*, *50*(14), 3636–3640. doi:10.1016/j.neuropsychologia.2012.09.016
- Higginson, C. I., Lanni, K., Sigvardt, K. A., & Disbrow, E. A. (2013). The contribution of trail making to the prediction of performance-based IADLs in Parkinson's disease without dementia. *Journal of Clinical and Experimental Neuropsychology*, *35*(5), 530–539. doi:10.1080/13803395.2013.798397
- Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: Onset, progression and mortality. *Neurology*, *17*(5), 427–442. doi:10.1212/WNL.17.5.427
- Ickenstein, G. W., Ambach, H., Klöditz, A., Koch, H., Isenmann, S., Reichmann, H., & Ziemssen, T. (2012). Static posturography in aging and Parkinson's disease. *Frontiers in Aging Neuroscience*, *4*, 20. doi:10.3389/fnagi.2012.00020

- Johnson, L., James, I., Rodrigues, J., Stell, R., Thickbroom, G., & Mastaglia, F. (2013). Clinical and posturographic correlates of falling in Parkinson's disease. *Movement Disorders*, 28(9), 1250–1256. doi:10.1002/mds.25449
- Kalinowski, M. A. (2008). "Eye" identifying vision impairment in the geriatric patient. *Geriatric Nursing*, 29(2), 125–132. doi:10.1016/j.gerinurse.2007.07.001
- Kerr, G. K., Worringham, C. J., Cole, M. H., Lacherez, P. F., Wood, J. M., & Silburn, P. A. (2013). Predictors of future falls in Parkinson disease. *Neurology*, 75, 116–124. doi:10.1212/WNL.0b013e3181e7b688
- Kunikowska, M., Zalewski, P., Klawe, J. J., Pawlak, J., Tafil-Klawe, M., Kedziora-Kornatowska, K., & Newton, J. L. (2014). Age-related changes in cognitive function and postural control in Parkinson's disease. *Aging Clinical and Experimental Research*, 26(5), 505–510. doi:10.1007/s40520-014-0209-z
- Leddy, A. L., Crowner, B. E., & Earhart, G. M. (2011a). Functional gait assessment and balance evaluation system test: Reliability, validity, sensitivity, and specificity for identifying individuals with Parkinson's disease who fall. *Physical Therapy*, 91(1), 102–113. doi:10.2522/ptj.20100113
- Leddy, A. L., Crowner, B. E., & Earhart, G. M. (2011b). Utility of the mini-BESTest, BESTest, and BESTest sections for balance assessments in individuals with Parkinson disease. *Journal of Neurologic Physical Therapy*, 35(2), 90–97. doi:10.1097/NPT.0b013e31821a620c
- Lee, J. M., Koh, S.-B., Chae, S. W., Seo, W.-S., Kwon, D. Y., Kim, J. H., . . . Park, W. K. (2012). Postural instability and cognitive dysfunction in early Parkinson's disease. *Canadian Journal of Neurological Sciences*, 39(4), 473–482. doi:10.1017/S0317167100013986
- Lin, C. C., Barker, J. W., Sparto, P. J., Furman, J. M., & Huppert, T. J. (2017). Functional near-infrared spectroscopy (fNIRS) brain imaging of multi-sensory integration during computerized dynamic posturography in middle-aged and older adults. *Experimental Brain Research*, 235(4), 1247–1256. doi:10.1007/s00221-017-4893-8
- Lyros, E., Messinis, L., & Papanthanasopoulos, P. (2008). Does motor subtype influence neurocognitive performance in Parkinson's disease without dementia? *European Journal of Neurology*, 15(3), 262–267. doi:10.1111/j.1468-1331.2007.02046.x
- Luque-Siles, C., Gallejo-Izquierdo, T., Jiménez-Rejano, J. J., de-la-Orden, S. G., Plaza-Manzano, G., López-Illescas-Ruiz, A., . . . Pecos-Martín, D. (2016). Reliability and minimal detectable change of three functional tests: Forward-lunge, step-over and sit-to-stand. *Journal of Physical Therapy Science*, 28(12), 3384–3389. doi:10.1589/jpts.28.3384
- Mak, M. K., Wong, A., & Pang, M. Y. (2014). Impaired executive function can predict recurrent falls in Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*, 95(12), 2390–2395. doi:10.1016/j.apmr.2014.08.006
- McDowd, J., Hoffman, L., Rozek, E., Lyons, K. E., Pahwa, R., Burns, J., & Kemper, S. (2011). Understanding verbal fluency in healthy aging, Alzheimer's disease, and Parkinson's disease. *Neuropsychology*, 25(2), 210–225. doi:10.1037/a0021531
- Mena-Segovia, J., Bolam, J. P., & Magill, P. J. (2004). Pendunculopontine nucleus and basal ganglia: Distant relatives or part of the same family? *Trends in Neurosciences*, 27(10), 585–588. doi:10.1016/j.tins.2004.07.009
- Miyamoto, S. T., Lombardi Junior, I., Berg, K. O., Ramos, L. R., & Natour, J. (2004). Brazilian version of the Berg Balance Scale. *Brazilian Journal of Medical and Biological Research*, 37(9), 1411–1421. doi:10.1590/S0100-879X2004000900017
- Morris, M. E., Menz, H. B., McGinley, J. L., Huxham, F. E., Murphy, A. T., Ianssek, R. et al. (2011). Falls and mobility in Parkinson's disease: Protocol for a randomised controlled clinical trial. *BMC Neurology*, 2011 Jul 31;11:93. 1–8. doi:10.1186/1471-2377-11-93
- NeuroCom International Inc. (2003). *Balance MasterSystem operator's manual, version 8.1*. Clackamas, OR: NeuroCom International.
- Nocera, J. R., Price, C., Fernandez, H. H., Amano, S., Vallabhajosula, S., Okun, M. S., . . . Hass, C. J. (2010). Tests of dorsolateral frontal function correlate with objective stability in early to moderate stage Parkinson's disease. *Parkinsonism & Related Disorders*, 16(9), 590–594. doi:10.1016/j.parkreldis.2010.08.008
- Nocera, J. R., Horvat, M., & Ray, C. T. (2010). Impaired step up/over in persons with Parkinson's disease. *Adapted Physical Activity Quarterly*, 27(2), 87–95. doi:10.1123/apaq.27.2.87
- Oude Nijhuis, L. B., Allum, J. H., Nanhoe-Mahabier, W., & Bloem, B. R. (2014). Influence of perturbation velocity on balance control in Parkinson's disease. *PLoS One*, 9(1), e86650. doi:10.1371/journal.pone.0086650
- Oshita, K., & Yano, S. (2017). Effect of haptic sensory input through a fluttering cloth on tandem gait performance. *Human Movement Science*, 2017 Oct;55:94–99. Epub 2017 Aug 12. doi:10.1016/j.humov.2017.08.008
- Park, S., Ko, Y. M., & Park, J. W. (2013). The correlation between dynamic balance measures and stance sub-phase COP displacement time in older adults during obstacle crossing. *Journal of Physical Therapy Science*, 25, 1193–1196. doi:10.1589/jpts.25.1193
- Ranchet, M., Broussolle, E., Poisson, A., & Paire-Ficout, L. (2012). Relationships between cognitive functions and driving behavior in Parkinson's disease. *European Neurology*, 68(2), 98–107. doi:10.1159/000338264
- Rochester, L., Yarnall, A. J., Baker, M. R., David, R. V., Lord, S., Galna, B., & Burn, D. J. (2012). Cholinergic dysfunction contributes to gait disturbance in early Parkinson's disease. *Brain*, 135, 2779–2788. doi:10.1093/brain/aws207
- Rossi, M., Soto, A., Santos, S., Sesar, A., & Labella, T. (2009). A prospective study of alterations in balance among patients with Parkinson's disease. Protocol of the postural evaluation. *European Neurology*, 61(3), 171–176. doi:10.1159/000189270
- Rossi-Izquierdo, M., Basta, D., Rubio-Rodríguez, J. P., Santos-Pérez, S., Ernst, A., Sesar-Ignacio, Á., . . . Soto-Varela, A. (2014). Is posturography able to identify fallers in patients with Parkinson's disease? *Gait & Posture*, 40(1), 53–57. doi:10.1016/j.gaitpost.2014.02.003
- Sanchez-Cubillo, I., Perianez, J. A., Adrover-Roig, D., Rodriguez-Sanchez, J. M., Rios-Lago, M., Tirapu, J., & Barcelo, F. (2009). Construct validity of the Trail Making Test: Role of task-switching, working memory, inhibition/interference control, and visuomotor abilities. *Journal of the International Neuropsychological Society*, 438–450. doi:10.1017/S1355617709090626
- Scalzo, P. L., Nova, I. C., Perracini, M. R., Sacramento, D. R., Cardoso, F., Ferraz, H. B., & Teixeira, A. L. (2009). Validation of the Brazilian version of the Berg Balance Scale for patients with Parkinson's disease. *Arquivos de Neuro-Psiquiatria*, 67(3B), 831–835. doi:10.1590/S0004-282X2009000500010
- Schmid, M., Conforto, S., Camomilla, V., Cappozzo, A., & D'Alessio, T. (2002). The sensitivity of posturographic parameters to acquisition settings. *Medical Engineering & Physics*, 24(9), 623–631. doi:10.1016/S1350-4533(02)00046-2
- Smulders, K., van Nimwegen, M., Munneke, M., Bloem, B. R., Kessels, R. P., & Esselink, R. A. (2013). Involvement of specific executive functions in mobility in Parkinson's disease. *Parkinsonism & Related Disorders*, 19(1), 126–128. doi:10.1016/j.parkreldis.2012.06.010
- Souza, C. de 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's disease. *Cognitive and Behavioral Neurology*, 26(1), 6–13. doi:10.1097/WNN.0b013e31828c5956
- Stocchi, F., Jenner, P., & Obeso, J. A. (2010). When do levodopa motor fluctuations first appear in Parkinson's disease? *European Neurology*, 63(5), 257–266. doi:10.1159/000300647
- Tombaugh, T. N. (2004). Trail Making Test A and B: Normative data stratified by age and education. *Archives of Clinical Neuropsychology*, 19(2), 203–214. doi:10.1016/S0887-6177(03)00039-8
- Valkovic, P., Abrahámová, D., Hlavacka, F., & Benetin, J. (2009). Static posturography and infraclinical postural instability in early-stage Parkinson's disease. *Movement Disorders*, 24, 1713–1714. doi:10.1002/mds.22396
- Vance, R. C., Healy, D. G., Galvin, R., & French, H. P. (2015). Dual tasking with the Timed "Up & Go" test improves detection of risk of falls in people with Parkinson disease. *Physical Therapy*, 95(1), 95–102. doi:10.2522/ptj.20130386
- Varalta, V., Picelli, A., Fonte, C., Amato, S., Melotti, C., Zatezalo, V., . . . Smania, N. (2015). Relationship between cognitive performance and motor dysfunction in patients with Parkinson's disease: A pilot cross-sectional study. *BioMed Research International*, 2015, id365959. doi:10.1155/2015/365959
- Visser, J. E., Oude Nijhuis, L. B., Janssen, L., Bastiaanse, C. M., Borm, G. F., Duysens, J., & Bloem, B. R. (2010). Dynamic posturography in Parkinson's disease: Diagnostic utility of the "first trial effect". *Neuroscience*, 30;168(2), 387–394. doi:10.1016/j.neuroscience.2010.03.068
- Williams, D. R., Watt, H. C., & Lees, A. J. (2006). Predictors of falls and fractures in bradykinetic rigid syndromes: A retrospective study. *Journal of Neurology, Neurosurgery, and Psychiatry*, 77(4), 468–473. doi:10.1136/jnnp.2005.074070
- Zalonis, I., Kararizou, E., Triantafyllou, N. I., Kapaki, E., Papageorgiou, S., Squouropoulos, P. et al. (2008). A normative study of the trail making test A and B in Greek adults. *The Clinical Neuropsychologist*, 22(5), 842–850. doi:10.1080/13854040701629301

Received February 6, 2017

Revised December 4, 2017

Accepted March 7, 2018