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Mayank Bhatt[1], Bhuvan Mahana[1], Jonathan J Marotta[2], Ji Hyun Ko[3], Douglas Everett Hobson[4] and Tony Szturm[5]*

[1]College of Rehabilitation Sciences, University of Manitoba, Winnipeg, MB, RR327-800 Sherbrook Street, R3A 1M4, Manitoba, Canada
[2]Professor, Perception and Action Lab, Department of Psychology, University of Manitoba, 190 Dysart Rd. Winnipeg, MB, Canada, R3N 0A9
[3]Assistant Professor, Department of Human Anatomy and Cell Science, Max Rady College of Medicine, Faculty of Health Sciences, University of Manitoba, Winnipeg, MB, SR432, Kleysen Institute for Advanced Medicine, 710 William Avenue, Winnipeg, Manitoba, R3E 3J7, Canada
[4]Assistant Professor, Department of Internal Medicine (Neurology), University of Manitoba, Neurologist, Movement Disorders Clinic, Deer Lodge Centre, Winnipeg, 200 Woodlawn Street, Winnipeg, R3J 2H7, Manitoba, Canada
[5]Associate Professor, Department of Physical Therapy, University of Manitoba, MB, RR319-800 Sherbrook Street, Winnipeg, R3A 1M4, Manitoba, Canada

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***Corresponding author:** Dr. Tony Szturm, Professor, Department of Physical Therapy, College of Rehabilitation Sciences, University of Manitoba, RR319-800 Sherbrook Street, Winnipeg, MB, R3A 1M4, Manitoba, Canada, Tel: (204) 787-4794; Fax: (204) 787-1227; E-mail: tony.szturm@med.umanitoba.ca

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Research Article

A new technique to test the effect of cognition on standing balance in Parkinson's disease

Abstract

Objectives: (a) To determine test-retest reliability of Game Assisted Rehabilitation System (GRS) for standing balance assessment during Single Task (ST) and Dual Task (DT) conditions in people with Parkinson Disease (PD). (b) To examine the discriminant validity of the GRS to evaluate the potential interaction effect of visuomotor and cognitive loads on standing balance in people with PD.

Design: The DT effect of a computer based Game-Assisted Rehabilitation System (GRS) on standing balance activities (DT) was evaluated in 30 individuals with PD (Hoehn and Yahr scale stage 2 and 3). Participants performed a series of game-based visuomotor cognitive tasks and head tracking while standing on sponge surfaces. Testing was conducted on two occasions spaced one week apart.

Setting: Data collection and analysis took place in clinical lab of the University.

Participants: Thirty participants diagnosed with PD and in stage 2 and stage 3 according to Hoehn and Yahr scale were recruited for the study from the local movement disorders clinic.

Main outcome measure: Test-retest reliability was assessed by two-way random model Intra-Class Correlation Coefficient (ICC) for sway path length and cognitive outcome measures such as total residual error, response time, movement variation and success rate.

Results: Moderate to high test-retest reliability was observed for performance measures of standing balance, visuomotor, and visuospatial executive cognitive functions. A significant DT effect over the majority of standing balance measures and the visuomotor tasks, was observed in individuals with PD.

Conclusions: This study demonstrated the reproducibility and validity of the GRS for studying DT interference as well as fall risk assessment in the PD population.

Clinical trial number: NCT03232996

Abbreviations

ANOVA: Analysis of Variance; BG: Basal Ganglia; COP: Centre of Pressure; ECF: Executive Cognitive Functions; EO: Eyes Open; FOG: Freezing of Gait; GRS: Game Assisted Rehabilitation System; ICC: Interclass Correlation Coefficient; mCTISB: Modified Clinical Test of Sensory Integration of Balance; MDC: Minimal Detectable Change; MV: Movement Variation; PD: Parkinson Disease; RT: Response Time; SOT: Sensory Organization Test; SPL: Sway Path Length; SR: Success Rate; TRE: Total Residual Error; UPDRS: Unified Parkinson Disease Rating Scale; VCG: Visuospatial Cognitive Gaming; VMT: Visuomotor Task

Introduction

The neurodegenerative process in Parkinson's Disease (PD) is not only restricted to the dopaminergic system but also contributes in the formation of abnormalities in cholinergic brain stem nuclei [1]. The combined effects of the degeneration in Basal Ganglia (BG) and other associated brain areas contributes to a number of motor and executive cognitive dysfunctions in PD [2]. Balance [3,4] and Executive Cognitive Function (ECF) [5,6], deteriorate in the early stages of PD. In addition, individuals with PD often need to exert executive

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control for routine (automated) motor tasks [7,8]. Dual-task conditions that require the simultaneous processing of both executive-cognitive functions and sensorimotor resources for balance are associated with increased risk of falls [9,10], as well as provoking the Freezing of Gait (FOG) [9].

Over 60% of individuals with PD fall each year and a significant portion of the same 60% will do so on multiple occasions [10,11]. For these individuals, the consequences of falling are often severe, leading to disability and, potentially, the loss of their independence.

Various tests and rating scales have been used to assess balance disorders in PD [11-13]. A number of studies that have used the analysis of Center of Pressure (COP) displacement in standing and have demonstrated the sensitivity of COP to quantify the level of balance performance as a function of multiple sensory conditions [14-16]. For example, tools such as the Sensory Organization Test (SOT) have been used to challenge specific sensory systems and to assess how well an individual integrates different sources of spatial information during standing balance tests [17]. The Modified Clinical Test of Sensory Interaction in Balance (mCTSIB) is an alternative which emulates the SOT conditions for assessing standing balance [18].

Both standing balance impairments and the decline in executive cognitive functions have been proven to contribute to increased fall risk and mobility limitations in individuals with PD. As such, there is a need to develop and validate both assessment and treatment tools that combine balance with executive cognitive activities. The dual-task balance assessment of individuals with PD have used cognitive tasks such as verbal fluency and simple number subtraction or digit recall [19-22]. These studies do not involve visuospatial processing and are limited to the individual brain areas recruited. Additional executive cognitive functions to consider in the analysis of DT effects on balance performance and mobility limitations include processing the spatial relations with respect to other objects, tracking moving objects, and visual search [20,23,24].

It should be noted that in previous DT balance studies [3,4] which used cognitive tasks-such as verbal counting and digit span-either did not report the cognitive outcome or the outcomes were assessed qualitatively. To overcome these limitations, the Game Assisted Rehabilitation System (GRS) was developed to assess and treat the decline in balance and visuospatial cognitive function for both individuals with PD and individuals experiencing the same as a result of aging [15,25,26]. The GRS assessment tool incorporates features of the mCTSIB by producing somatosensory disorientation and increased balance demands with help of a compliant sponge pad. The visuomotor cognitive tasks used in the GRS require continuous visual searching and tracking of moving objects on a computer display. Test-retest reliability of the GRS assessment tool has been established for older adults with fall histories [24].

The first objective of the present study was to establish test-retest reliability and the Minimal Detectable Change (MDC) of balance and visuospatial cognitive performance measures when tested during DT conditions in individuals with PD. The second objective, was to examine the effects of task condition and stage of disease on balance and visuospatial cognitive performance measures. It was hypothesized that task condition (single versus dual) and disease severity (stage 2 versus stage 3 PD) would result in increased DT interference of both balance and visuospatial cognitive performance.

Methods

Thirty participants diagnosed with PD (UK brain bank), aged 55 to 70 years, and in stage 2 or 3 (Hoehn and Yahr scale) were recruited from the local movement disorder clinic. Participants were eligible to be included in the study if they were able to walk at least 50 meters without any assistance. Exclusion criteria included any significant cognitive impairment (Montreal Cognitive Assessment scores <26), any neurological disorders aside from PD, as well as any musculoskeletal or psychiatric disorders. The Human Research Ethics Board at the university approved the study and all participants provided informed consent.

The sample size for this study was computed using Table 1, of Zou [27]. Thirty participants were required for an ICC value of 0.8, assurance of 70%, and class interval half-width of 0.15.

Testing protocol and equipment

Participants were instructed to stand still for 30 seconds while standing on a compliant sponge surface under the following test conditions: a) Eyes Open (EO), b) Performing a Visuomotor Tracking (VMT) task and c) Performing two Visuospatial Cognitive Gaming (VCG) tasks. The VMT and VCG tasks described below were also performed while sitting (i.e. single task condition) and the order of the tests was randomized. Participants returned 5-7 days later and repeated the tests. Care was taken to repeat the tests at the same time of day and during the on-phase of their medications.

A force sensor pressure mat with a sampling rate of 50Hz (Vista Medicals) was placed on top of the sponge pad and was used to record the COP displacements during the standing tasks [24,28]. Two computer applications were developed for the DT balance assessment. A brief description of computer based

Table 1: Demographic and Clinical Data.

Demographic Data	Mean±SD
Total Participants	30
Age (years)	64.92±6.21
Male/Female	19/11
Time since diagnosis (years)	5.60±4.44
Hoehn and Yahr scale	2.50±0.50
Participants at Stage-2	15c
Participants at Stage-3	15
UPDRS (Total)	36.11±12.31
UPDRS (Motor)	25.88±8.79
MoCA	28.92±1.07

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cognitive tasks is presented below. Details of the applications and protocols can be found in Szturm et al., [24].

The VMT module, as shown in Figures 1A,B, involved tracking a visual target that moved horizontally on a computer display for several cycles. Two cursors of different shapes appeared on the monitor. The target was a circle, its motion was computer controlled. It moved at a predetermined frequency of 0.5Hz with an amplitude of 80% of the monitor width. The second cursor was a rectangle which was enslaved to head rotation via a head-mounted inertial-based motion mouse (Scoop pointer mouse, Hillcrest Lab). Participants were instructed to move and overlap the rectangle head-controlled cursor with the target circle for several cycles. The computer application generated a logged data file to record coordinates of the target cursor and the head rotation at 80Hz. This was used for offline analysis described below.

The VCG module as shown in Figure 1C, was for the purpose of moving a game paddle horizontally via head rotation horizontally to interact with the moving game objects. The game objects were categorized as designated targets or designated distractors. The game objects appear at random locations at the top of the display every 2 seconds and moved to the bottom of the display. Participants responded by moving the game paddle to catch the target objects while avoiding the distractors. Two different difficulty levels were used; VCG1, here the trajectories of the game objects were vertical and VCG-2, where the targets moved in a diagonal path from top to bottom. A logged data file was generated that synchronously recorded the coordinates of the game paddle and target objects at a sampling rate of 100Hz. Prior to testing, the participants were allowed to play the tracking and game tasks while sitting for a few minutes to become familiar with each task.

The Unified Parkinson's Disease Rating Scale (UPDRS) was completed in the first test session.

Data analysis

The following outcome measures were quantified:

Balance performance measures: The total COP Sway Path Length (SPL) over 30 seconds was recorded. Increases in SPL were interpreted as decreases in stability [15,28]. MATLAB (The Math Works, Natick, MA, version 2017a) was used to compute the outcome measures described above.

VMT performance measures: As shown in Figure 1B, synchronous plots of the target motion and user's head rotation (rectangle cursor) for a typical visuomotor task were generated by the computer application. The Total Residual Error (TRE) was determined by computing the difference between the trajectories of the target and head cursor motions [24]. The first two cycles of the visuomotor tracking tasks were excluded to allow the participant to acquire the moving target and begin tracking.

VCG performance measures: As depicted in Figure 1E, overlay trajectories of game paddle displacements (head movements) for all game events in one 60 second game session

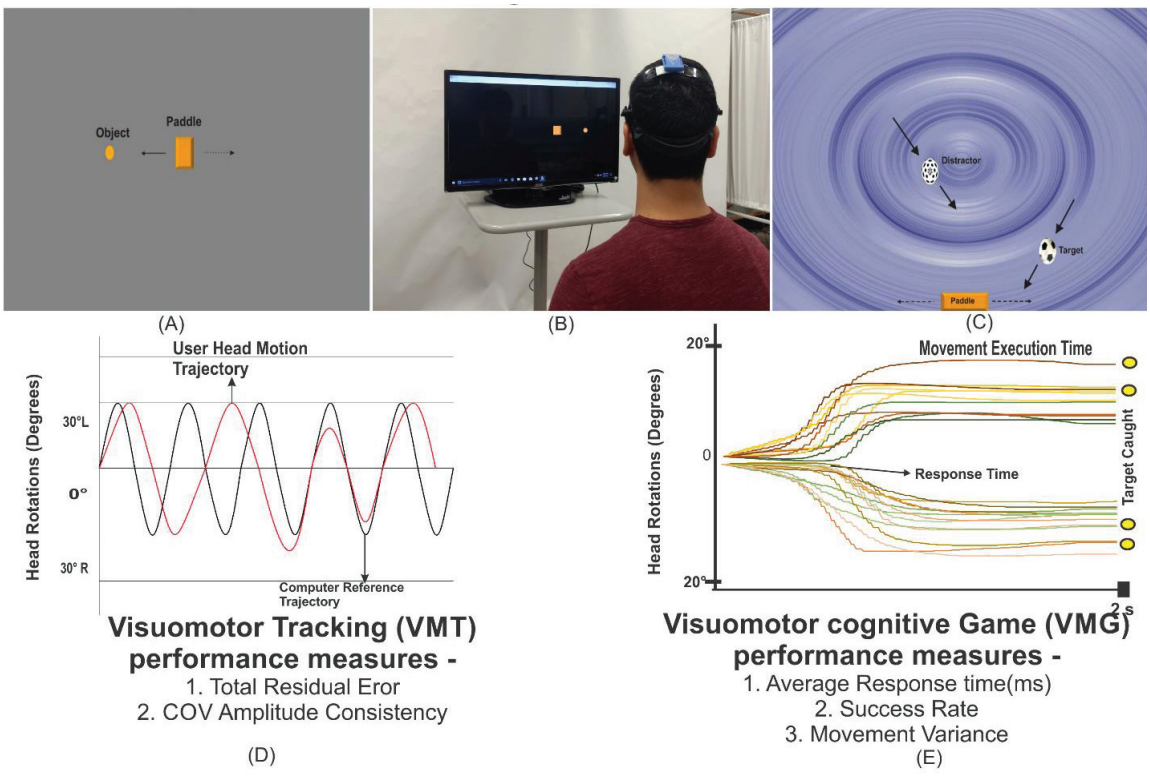

Figure 1: VMT and VMG task for assessment of DT condition and outcome measures.

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Each game event lasted for two seconds from initial target appearance to target disappearance. Based on time indices of target appearance and disappearance the software segmented all 30 game movement responses, and sorted the movement traces by direction. One half of the game movement responses are in left and right direction. Thus, the software produces multiple standardized contextual movement events (player's actions) in each of the above directions. For a comprehensive description of the game movement indexing and segmentation see Lockery et al., [29]. The outcome variables determined were average Response Time (RT), Success Rate (SR) and Movement Variation (MV). The average RT provided time from target appearance to the start of the game paddle movement (head rotation). The SR determined the successful targets caught in 60 sec. The MV quantified the variability in neck rotation from left to right during 60seconds of gameplay. A paired sample t-test statistical analysis revealed no significant difference in RT or MV between left and right movements. Therefore only one movement direction was considered for analysis.

Statistical analysis

The data sets were confirmed using the Shapiro-Wilk normality test and the relative test-retest reliability was assessed using a two-way random model Intra-Class Correlation Coefficient (ICC). Intra-Class Correlation Coefficient values above 0.9 were interpreted as excellent, 0.75-0.9 as good, 0.5-0.75 as moderate, and below 0.5 as poor reliability [30]. Absolute reliability was analyzed using MDC. Systematic errors between the test periods were evaluated using two tailed paired t-tests.

Discriminative validity was established using a repeated measures ANOVA to evaluate the effect of task condition (single versus DT), disease severity (stage 2 versus 3 on Hohen and Yahr Scale), and the interaction of task with/in conjunction with disease state. For VMT and VCG performance measures, the single task condition was sitting, and the DT condition was standing on the above described sponge. SPSS software for Windows, version 20.0 (SPSS Inc. Chicago) was used for all statistical analysis procedures.

Results

Table 1 presents the demographic and clinical data of the participants. A total of 30 participants with PD took part in the study with an average age of 65.92 years. Fifteen participants were in stage 2 and fifteen participants were in stage 3 of PD, as per the Hoehn and Yahr scale. There were 19 male and 11 female participants. The average time elapsed since initial diagnosis of study participants was 5.60 years. Average UPDRS motor performance score of all participants was 25.88.

Test-retest reliability

Tables 2,3 present ICC and MDC values along with the group means and Standard Deviations (SD) for the balance and VMT/VCG performance measures respectively. Moderate to good test-retest reliability with ICC values ranging from 0.6 to 0.9 was exhibited by SPL. The MDC percentage values were relatively high, ranging from 57% to 80%. Total residual error for the VMT tasks exhibited good test-retest reliability with ICC values of 0.88 when sitting and 0.81 when tested standing on the sponge surface. The MDC% values for TRE were 30% in sitting tests and 36% in standing. Good to excellent test-retest reliability was observed for SR with ICC values greater than 0.8. For both VCG tasks Avg. RT and MV showed moderate to good test-retest reliability with ICC values ranging from 0.5 to 0.88. The majority of the MDC percentage values were below 20% for Avg. RT and SR but were higher for MV with a range of 20%-40%. There was no significant difference in SPL, TRE, or the VCG outcome measures between tests one and two.

The test-retest analysis for SPL was repeated separately for stage 2 and stage 3 participants to examine effect of group

Table 2: Test-retest reliability values of Sway Path Length for the DT test conditions. Data is first presented for the 30 participants and then separately for the stage 2 and 3 participants.

Condition	Test 1 Mean (SD)	Test 2 Mean (SD)	ICC Value (95% CI)	MDC (% of mean)	t-test
Whole Group					
Eyes Open	2.56 (1.23)	3.42 (2.04)	0.7 (0.27 – 0.86)	1.89 (74)	0.008
VMT task	4.15 (1.91)	4.88 (2.78)	0.61 (0.12 – 0.83)	3.3 (80)	0.11
VMG-1 task	3.71 (1.84)	4.08 (1.81)	0.76 (0.47 – 0.89)	2.49 (67)	0.09
VMG-2 task	4.35 (1.70)	4.18 (2.34)	0.72 (0.37 – 0.87)	2.49 (57)	
Stage-2 Participants with PD					
Eyes Open	2.74 (1.60)	3.43 (2.18)	0.85 (0.54 – 0.95)	1.71 (62)	0.10
VMT task	4.01 (2.15)	4.66 (2.70)	0.89 (0.59 – 0.97)	1.97 (49)	0.63
VMG-1 task	3.59 (2.15)	3.90 (1.69)	0.85 (0.22 – 0.96)	2.3 (64)	0.77
VMG-2 task	3.94 (1.72)	3.82 (1.69)	0.91 (0.66 – 0.98)	1.43 (36)	0.39
Stage -3 Participants with PD					
Eyes Open	2.38 (0.72)	3.59 (1.95)	0.81 (0.06 – 0.95)	0.87 (37)	0.02
VMT task	4.29 (1.72)	5.34 (2.87)	0.72 (-015 – 0.93)	2.52 (59)	0.23
VMG-1 task	3.83 (1.56)	4.44 (1.87)	0.84 (0.48 – 0.95)	1.72 (45)	0.08
VMG-2 task	4.75 (1.63)	4.73 (2.76)	0.8 (0.23 – 0.93)	2.02 (42)	0.27

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Table 3: Test-retest reliability of visuomotor task (VMT) and visuomotor gaming (VMG) task performance.

Outcome Variables	Condition	Test 1 Mean (SD)	Test 2 Mean (SD)	ICC Value (95% CI)	MDC (% of mean)	T- Test (p-value)
Visuomotor Tracking (VMT) task performance measures						
TRE (%)	Sitting	11.27 (3.58)	10.95 (4.14)	0.88 (0.74 – 0.95)	3.43 (30.43)	0.26
	Sponge standing	12.61 (3.78)	12.02 (3.50)	0.81 (0.58 – 0.91)	4.56 (36.00)	0.16
Visuomotor Gaming (VMG) task performance measures						
Avg. RT (s)	Sitting (VMG-1)	0.61 (0.06)	0.58 (0.06)	0.50 (-0.07 – 0.77)	0.12 (19.6)	0.06
	Sponge standing (VMG-1)	0.59 (0.08)	0.56 (0.08)	0.76 (0.46 – 0.89)	0.10 (16.90)	0.06
	Sitting (VMG-2)	0.63 (0.07)	0.62 (0.06)	0.85 (0.68 – 0.93)	0.07 (11.06)	0.06
	Sponge standing (VMG-2)	0.64 (0.05)	0.58 (0.06)	0.62 (-0.1 – 0.85)	0.09 (13.71)	0.001
SR (%)	Sitting (VMG-1)	92.27 (9.35)	92.46 (13.43)	0.68 (0.26 – 0.85)	14.18 (15.36)	0.47
	Sponge standing (VMG-1)	89.90 (12.10)	92.79 (11.47)	0.88 (0.72 – 0.95)	10.59 (11.77)	0.06
	Sitting (VMG-2)	82.89 (15.38)	86.72 (14.16)	0.85 (0.65 – 0.93)	16.49 (19.89)	0.06
	Sponge standing (VMG-2)	77.65 (16.11)	86.89 (13.76)	0.80 (0.23 – 0.91)	19.95 (25.70)	0.001
MV (%)	Sitting (VMG-1)	15.7 (3.18)	16.05 (3.32)	0.63 (0.09 – 0.85)	5.21 (33.14)	0.37
	Sponge standing (VMG-1)	17.4 (3.18)	15.90 (2.40)	0.60 (-0.002 – 0.84)	5.57 (32.01)	0.06
	Sitting (VMG-2)	20.21 (4.02)	18.90 (3.18)	0.50 (-0.37 – 0.70)	8.62 (42.65)	0.27
	Sponge standing (VMG-2)	21.99 (4.46)	22.12 (4.19)	0.85 (0.67 – 0.93)	4.78 (21.73)	0.06

variance on the ICC and MDC values. The ICC values improved when computed for each stage separately with a range of 0.61-0.76 for the entire group to 0.85-0.91 for stage 2, and 0.72-0.84 for stage 3. Similarly, the MDC% decreased when computed for each stage separately with a range of 57%-80% for the entire group to 36%-51% for stage 2, and 42%-52% for stage 3.

Validity

The statistical results to the effect of task condition and disease stage on SPL are presented in Table 4. The group means as well as the SD of SPL by task condition and disease stage are presented in Figure 2. There were significant effects of task conditions on the magnitude of SPL, however, there was no effect of disease stage on SPL during either single-or dual-task conditions. Post hoc analysis revealed a significant increase in SPL while performing the VMT and VCG tasks as compared to the stand only condition (Table 5). In addition, there was a significant increase in SPL with increasing VCG difficulty level. But there was no difference in magnitude of SPL between VMT and VCG conditions.

The statistical results of the effect of task condition and disease stage on VMT and VCG task performance measures are presented in Table 6. Group means and SD of the VMT and VCG performance measures by task condition and disease stage are presented in Figure 3,4.

There was a significant increase in TRE when participants were standing on the sponge as compared to sitting. Participants showed a significant decrease in SR and a significant increase MV when standing on the sponge as compared to sitting. However, there was no effect of task condition on RT. Additionally, there was no effect of disease stage on TRE, SR, MV, or RT while sitting or when standing on the sponge pad.

Discussion

The primary objective of the study was to determine the test-retest reliability and discriminate validity of the

Table 4: Statistical results of the effect of task condition, and disease severity on standing balance.

Task	Task condition *F, p- value, η2*	Stage of PD *F, p- value, η2*	Interaction *F, p- value, η2*
DT–Standing balance performance measures			
SPL			
EO vs DT-VMT	34.10, 0.001, 0.59	0.005, 0.95, 0.001	1.37, 0.25, 0.05
EO vs DT-VMG-1	21.61, 0.001, 0.47	0.01, 0.92, 0.001	1.47, 0.24, 0.06
EO vs DT-VMG-2	35.93, 0.001, 0.6	0.20, 0.66, 0.008	3.81, 0.05, 0.14

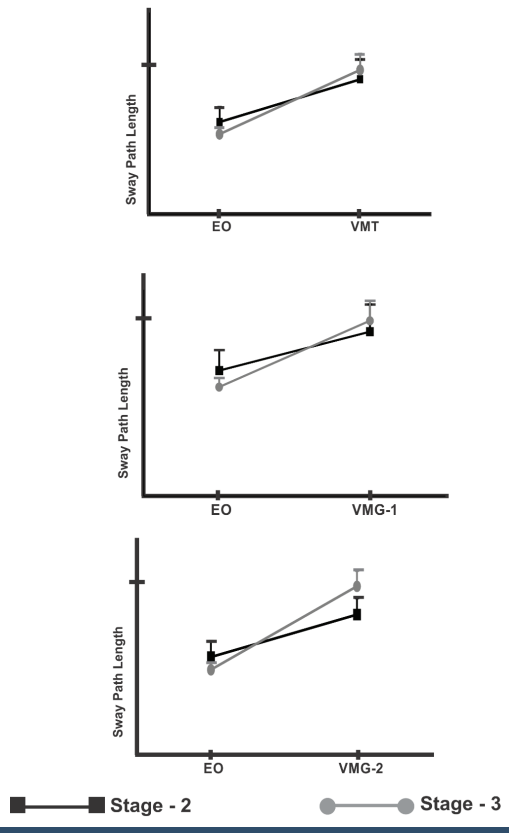

Figure 2: ANOVA line graphs for stage wise sway path length during DT condition as compared to ST.

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Table 5: Post hoc Analysis of ANOVA for change in sway path length under different tasks and on effect of stage of disease.

Task pairs	Whole Group		Stage -2 PD		Stage-3 PD	
	t (25)	p-value	t (12)	p-value	t (12)	p-value
EO vs VMG-1	-4.15	0.001	-4.60	0.001	-2.43	0.03
EO vs VMG-2	-5.31	0.001	-5.68	0.01	-3.05	0.001
EO vs VMT	-4.16	0.001	-5.79	0.001	-4.34	0.001
VMG-1 vs VMG-2	-2.94	0.01	-2.73	0.01	-1.04	0.05
VMG-1 vs VMT	-0.78	0.45	-1.43	0.17	-2.03	0.07
VMG-2 vs VMT	0.65	0.53	0.51	0.62	-0.21	0.84

Table 6: Statistical results of the effect of task condition, and disease severity on VMT and VMG task performance measures.

Task	Task condition *F, p- value, η2*	Stage of PD *F, p- value, η2*	Interaction *F, p- value, η2*
VMT performance (sitting vs standing on sponge)			
TRE	5.01, 0.04, 0.17	2.73, 0.11, 0.10	0.05, 0.83, 0.002
VMG performance (sitting vs standing on sponge)			
Avg. RT (VMG-1)	2.43, 0.13, 0.09	2.50, 0.13, 0.09	0.09, 0.76, 0.004
Avg. RT (VMG-2)	0.28, 0.59, 0.01	1.19, 0.28, 0.05	0.33, 0.57, 0.01
SR (VMG-1)	0.80, 0.37, 0.03	0.69, 0.41, 0.03	0.02, 0.9, 0.001
SR (VMG-2)	8.54, 0.007, 0.26	0.52, 0.48, 0.02	2.27, 0.15, 0.09
MV (VMG-1)	3.56, 0.07, 0.13	0.08, 0.79, 0.003	0.01, 0.98, 0.01
MV (VMG-2)	7.79, 0.01, 0.25	0.63, 0.44, 0.03	0.60, 0.44, 0.03

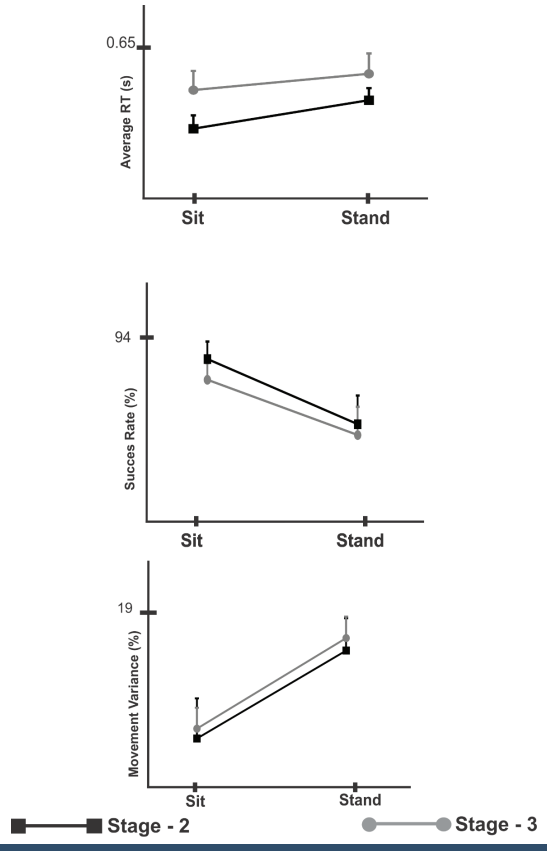

Figure 3: ANOVA line graphs for stage wise VCG performance during DT condition as compared to ST.

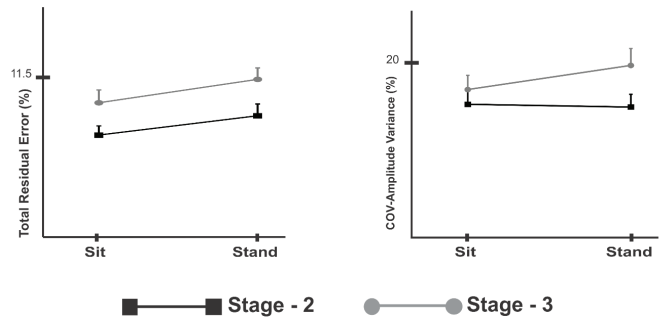

Figure 4: ANOVA line graphs for stage wise VMT performance during DT condition as compared to ST.

GRS assessment tool. With few exceptions, the GRS showed moderate to good test-retest reliability for the balance and visuomotor cognitive task performance measures. Some of the DT balance outcome measures had high MDC% values greater than 60%. When evaluating the effectiveness of treatment programs, performance measures having high MDC% values would require a greater amount of change from pre- to post-intervention in order to be considered significant. Group variability directly affects the values of MDC as the greater the difference between subject variability will result in higher MDC [31].

When the analysis was repeated for each stage separately, the group variation decreased and MDC% values were

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significantly reduced. The highest MDC% values for the SPL during the DT task decreased from 60% to 36% in the stage 2 group and from 42% in the stage 3 group. The majority of MDC% values for VMT and VCG performance measures were much lower than the SPL in the range of 10%-20%. An MDC% value of 10%-20% would be considered an acceptable level to detect meaningful change due to an intervention.

The results gained from this study demonstrated a significant increase in the magnitude of COP displacement during all dual-task conditions. Other studies have also reported an increase in COP displacement during standing while performing a verbal fluency task [20], a digital span recall task [22] and a backward counting task [19]. The present study also observed a significant decline in the performance of the VMT and VCG tasks when tested in standing on the compliant sponge surface versus sitting. The studies by did not quantify the performance of the cognitive task [19,20]. In contrast to the present study, the findings of [22], did not observe a decline in the percentage of digits correctly recalled by the participants with PD when testing while standing on a compliant sponge surface versus sitting. The VMT and VCG tasks used in the present study required visuospatial cognitive processing in conjunction with head rotations to interact with the moving targets. It should be noted that many real-life tasks involve head movements to search and track for various objects. The VMT task requires real-time sensory guidance; in this case, visual feedback of the spatial locations of two moving objects as well as a continuous motor response to keep them overlapped for several cycles. The VCG task required a visual search to identify a moving object as a target or a distractor (cognitive inhibition) and to estimate the targets final position (i.e. accuracy requirement). The results obtained from the current study also demonstrate that the magnitude of COP displacement (DT interference) was sensitive to the level of difficulty between VCG1 and VCG2. Objective evaluation of the concurrent cognitive task is an important feature of the GRS assessment tool as it helps to determine the level of engagement in DT situations and provides important information about the DT effects on balance of different types and levels of information processing loads.

Different theoretical models have been proposed to explain DT interference [32]. The cross-domain competition or capacity sharing model states that many motor and cognitive tasks challenge the same cortical processing resources [33]. If the attention and information processing loads of the two tasks is greater than the available resources, then there will be a decline in one, or both, of the motor and cognitive tasks.

Maintaining balance while standing on a compliant sponge surface requires attention resources for continuous monitoring of body motion as well as to generate timely corrective responses to counter excessive body sway. This requires the processing and organization of spatial information from multiple sensory systems. The visuomotor tasks used in the present study required sustained visual attention and foveation of the moving targets to maintain their overlap, while also challenging aspects of executive cognitive function, i.e. cognitive inhibition.

The increased attentional demands and processing of spatial information to prevent falling would compete for resources required to perform the VMT and VCG tasks and vice versa. Therefore, the cross-domain competition model best explains the present findings; significant DT interference on both balance and visuomotor cognitive performance. Individuals with PD often need to exert executive control for routine motor tasks [9,21], which makes them susceptible to increased DT interference and consequently increased risk of falling [10,11].

It should be noted that all participants were tested in the "On-state" of their medication regime and that the results may be different during the Off-state.

Limitations

One limitation of the GRS is that it requires an inertial-based computer mouse, a computer, and basic knowledge of computer operation. At least 30 degrees of head rotation in both left and right direction is required to use the inertial-based mouse as the input device to control the position/motion of the game paddle. Individuals with limited range of head rotation due to rigidity or pain may find this difficult to achieve.

Conclusion

The moderate to high ICC values along with the lack of systematic errors in the measures indicate that this tool has the ability to repeatedly record reliable DT balance data in individuals with stage 2 and 3 PD. The use of interactive computer applications provides a flexible, standardized method to produce and evaluate a wide range of executive cognitive activities while performing complex motor behaviors such as balancing under demanding conditions. Quantification of visuocognitive-motor interactions has potential to detect balance and mobility limitation in PD.

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