Evaluation of a Computer Game Based Rehabilitation System for assessment of balance and gait impairments in individuals with Parkinson’s disease.

by

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Abstract

Impairments to standing balance, gait and executive-cognitive functions are commonly observed in Parkinson's disease (PD) population. These problems are often exacerbated during the Dual-Task (DT) conditions that require simultaneous processing of executive-cognitive functions and sensorimotor resources. Lack of a reliable and valid instrument is a major limitation in DT assessment for PD population. A Computer Game Based Rehabilitation System (CGBRS) has been developed for simultaneously assessing balance, gait and executive cognitive functions in individuals with PD. The Main objectives of this study were to examine test-retest reliability and construct validity of CGBRS for evaluating the balance, gait, visuo-motor and visio-spatial executive cognitive functions under both single and DT conditions in individuals with PD. The present study also compared the effects of DT-interference on gait and executive-cognitive functions for stage-2 (mild) and stage-3 (moderate) individuals with PD. Twenty-six individuals with PD (stage-2 and 3, Hoehn and Yahr scale) were recruited for this study and examined on two separate occasions (one week apart). Moderate to high test-retest reliability was observed for performance measures of standing balance, gait, visuo-motor and visuospatial executive cognitive functions. A significant DT-effect was found on the majority of standing balance, gait, VMT and VMG performance measures in individuals with PD. Significant differences between stage-2 and stage-3 PPD were observed during single and DT-walking conditions. This study demonstrated the reproducibility and validity of the CGBRS for studying DT-interference and fall risk assessment in PD population.
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Dedication

I dedicate this thesis to my parents and my sister – Mr. Dinesh Bhatt, Mrs. Samriti Bhatt and Srishti.
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Figure 13 – Graphs displaying the visuomotor tracking task performance in stage-2 and stage-3 PPD.86

Figure 14 – Graphs displaying the visuomotor gaming task performance in stage-2 and stage-3 PPD.88
List of abbreviations

ANOVA: Analysis of variance

A-P: Antero-Posterior

Avg.: Average

BBS: Berg balance scale

BG: Basal ganglia

CGBRS: Computer Game based Rehabilitation System

COP: Center of foot pressure

CTSIB: clinical test of sensory interaction in balance

DT: Dual-task

ECF: Executive cognitive functions

FAB: Frontal assessment battery

FOG: Freezing of gait

FOGQ: Freezing of gait questionnaire

FSA: Force sensor application

H-Y Scale: Hoehn and Yahr scale of PD classification

ICC: Intraclass Correlation
MDC: Minimal detectable change

MDC%: MDC represented as percentage of group mean for test-1

M-L: Medio-lateral

MOCA: Montreal cognitive assessment

MovVar: Movement variance

NS: Not significant

PD: Parkinson’s disease

PPD: Participants with PD

RMS: Root mean square

RT: Response time duration

S_VMT: Standing on sponge while performing VMT

S_VMG-1: Standing on sponge while performing VMG-1

S_VMG-2: Standing on sponge while performing VMG-2

SD: Standard deviation

SEM: Standard error of means

SEm: Standard error of measurement

SL: Step length
SO: Stand only

SOT: Sensory organization test

SrT: Stride time

ST: Single task

SwT: Swing time

TMT: Trail making test

TUG: Timed up and go

UPDRS: Unified Parkinson’s disease rating scale

UPDRS-3: Unified Parkinson’s disease rating scale part-3 (motor examination part)

VMT: Visuomotor Tracking

VR: Virtual reality

VMG: Visuomotor gaming task

VMG-1: Easy VMG task

VMG-2: Difficult VMG task

W_VMT: Walking while performing VMT

W_VMG-1: Walking while performing VMG-1

W_VMG-2: Walking while performing VMG-2

WO: Walk only
Chapter 1. Introduction

Parkinson’s disease (PD) is the second most common adult-onset chronic neurodegenerative disorder, after Alzheimer’s disease (1). Currently, more than 100,000 Canadians are diagnosed with Parkinson’s disease (2). By the year 2031, it is estimated that these figures will soar up to more than 163,000 (3).

The pathophysiological hallmark of Parkinson’s disease (PD) is the progressive loss of dopaminergic neurons and the presence of lewy bodies in the substantia nigra pars compacta (4). This leads to the depletion of dopamine in various regions of the basal ganglia (BG) (5). Recent studies have shown that neurodegeneration is not only restricted to the dopaminergic pathways but it also involves cholinergic, serotonergic and noradrenergic pathways in people with PD (PPD) (6). The basal ganglia is known to form extensive neural interconnections with many cortical and sub-cortical regions, which are responsible for processing various motor, executive and limbic functions. Damage to the basal ganglia as seen in PD, leads to major disturbances in balance, mobility and executive cognitive function (7).

The primary cause of neurodegeneration related to PD is still largely unknown (8). Some studies have shown PD to be a genetically inherited disorder (9,10), while others have linked environmental factors like exposure to herbicide, pesticides and heavy metals like manganese to PD (11). Researchers have also related the death of dopaminergic neurons to oxidative stress, mitochondrial dysfunction and microglial activation (12,13). Accumulation of lewy bodies has always been a characteristic feature of PD, but their association with the pathogenesis of Parkinson’s disease is still not clearly established (14). Presently, no imaging techniques or
biochemical testing procedures can reliably diagnose PD in an individual. Diagnosis of PD is purely based on medical history as well as the physical and neuropsychological clinical evaluations performed by a neurologist (5).

Parkinson’s disease is characterized by three cardinal motor signs (14,15). First, tremors are prominently observed in the distal joints giving rise to the characteristic "Pill Rolling" and can also be observed at the lips, chin, jaw and lower extremity which may disappear with movement or during sleep (16). Second, PPD exhibit ratchet like “Cogwheel” rigidity (17). In PD patients, rigidity is often observed in axial as well as limb musculature with flexor muscles exhibiting more rigidity than the extensor muscles (15). A third cardinal sign of PD is Bradykinesia, an overall slowness in movement often characterized by impaired planning, initiating and executing a particular movement (6). Bradykinesia can result in reduced facial expressions, reduced blinking of eyes, dysarthria (slow and monotonous speech), reduced speed of walking as well as arm swings (18). These motor signs lead to severe balance and mobility impairments, which are often observed from the early stages of PD (19–23).

Along with motor deficits, patients with PD also exhibit damage to Executive-cognitive functions (ECF). In PD, impairment to the ECF results from progressive degeneration of the dopaminergic frontostriatal neural pathway which connects the basal ganglia with dorso-lateral prefrontal cortex of the brain (24,25). In an individual, physical as well as executive-cognitive resources are important for inducing safe balance and mobility behavior. During Activities of daily living, an individual encounter various situations in which walking or balance must be combined with a cognitive task like – navigation in space, negotiating terrains and obstacles, tracking visual targets, reading, or recall (26,27). In PD, such Dual-task (DT) situations
especially the DT-walking tasks are often associated with increased risk of falls and freezing of gait (FOG) (28).

Brain imaging techniques have shown that PPD over-activate several regions of the prefrontal cortex, premotor cortex, parietal cortex and temporal cortex during the DT processing when compared with healthy controls. This finding strongly supports the theory of "reduced automaticity" in PD individuals and over-dependency on the attentional and executive-cognitive function resources for learning a new task (29,30). Several studies that examined the neural mechanism behind the improvement of DT ability have found a reduction in the cortical activity especially in the dorsolateral prefrontal cortex, posterior lateral prefrontal cortex and the basal ganglia following the dual task training (31,32). Dual-task paradigm has been extensively used for assessing and training both motor as well as cognitive aspects of mobility in PPD (33–41).

Present study established the accuracy, reliability and validity of a Computer Game Based Rehabilitation System (CGBRS) to evaluate and assess both motor as well as the executive cognitive function in the PD population. CGBRS comprises of a treadmill instrumented with the pressure mapping system and a computer gaming subsystem. Treadmill ensures an effective examination of gait while the computer gaming application is specially designed to challenge various aspects of ECF.
Chapter 2. Literature Review

2.1: Standing balance in individuals with PD

Several research studies have applied Sensory Organization Tests (SOT) to evaluate an individual’s capacity for utilizing visual, vestibular and sensorimotor resources to maintain a stable standing balance (42–44). During SOT, all participants perform six balance tasks:

1. SOT 1 – Maintaining a stable standing balance on a firm surface with eyes open. Visual, vestibular, as well as somatosensory resources are available during this task.
2. SOT 2 – Maintaining a stable standing balance on a firm surface with eyes closed. Only the visual system is eliminated during this task.
3. SOT 3 – Maintaining a stable standing balance on a firm surface with sway referenced visual surrounding. Only the visual system is altered during this task.
4. SOT 4 – Maintaining a stable standing balance on a dynamic sway-referenced support surface with eyes open. Somatosensory inputs are altered during this task.
5. SOT 5 – Maintaining a stable standing balance on a dynamic sway-referenced support surface with eyes closed. Somatosensory inputs are altered while the visual system is completely eliminated during this task.
6. SOT 6 – Maintaining a stable standing balance on a dynamic sway-referenced support surface with sway referenced visual surrounding. Both somatosensory and visual resources are altered during this task.
For each task condition, the average magnitude of Center of Foot Pressure (COP) sway is computed to evaluate the standing balance performance (45,46).

A study Nocera, Horvat, & Ray, 2009 (47) compared the sensory organization test (SOT) performance of ten PPD and ten healthy age-matched controls using the Equitest system. Participants in the PD group were all at stage-2 -3 on the Hoehn and Yahr scale (H – Y Scale). All participants showed a significant surge in the magnitude of COP sway during SOT 4, SOT 5 and SOT 6 conditions. Many studies in the past have reported an excessive COP sway in PD group during SOT5 and SOT 6 standing tasks when compared with age matched controls similar (48–50).

Modified Clinical Test of Sensory Interaction in Balance (CTSIB) test is an inexpensive and easier alternative to emulate the SOT conditions for assessing standing balance in PD population (51,52). In the CTSIB a sponge surface is used to create the sway referenced surface which disturbs the somatosensory inputs coming from the ground (53). A recent study compared the modified clinical test of sensory interaction in balance (CTSIB) for PPD and healthy age-matched controls (54). Standing balance was evaluated for fourteen PPD with freezing of gait (FOG), seventeen participants without FOG and twenty-one healthy controls using the Biodex force sensor platform. All individuals were tested in 4 conditions which included standing on a fixed surface (Eyes open/Eyes Closed) as well as standing on a sponge surface (Eyes Open/Eyes Closed). FOG group showed a relevant increase in COP sway during eyes-open, standing over the sponge task when compared with standing on a sponge as compared to individuals without
FOG and healthy controls. Notably, all three groups showed an increase in the COP excursions during the sponge standing with eyes closed condition, but no significant group effect was found.

A few research studies have evaluated the effect of dual-task on the standing balance performance in PPD (54–56). Fernandes et al., 2015 (57) looked at how the standing balance is affected by a concurrent cognitive task in stage 1-3 of H-Y scale PPD and healthy age matched controls. Balance performance was tested under three conditions – standing with eyes open, standing with eyes closed while performing a verbal fluency task. All standing tasks were performed on a pressure sensitive platform and center of foot pressure (COP) sway was quantified. The PD group exhibited a significantly increased COP sway during standing with eyes closed and under the DT-condition as compared with standing with eyes-open condition. When compared with healthy controls, the PD group exhibited higher COP displacements in both Anterio-Posterior (AP) and Medial-Lateral (ML) directions for each standing task.

Several research studies have evaluated balance in PPD using conventional clinical scales and measures (58–61). Löfgren, Benka Wallén, Sorjonen, Conradsson, & Franzén, 2017 (63) compared the Mini-Balance Evaluation System or Mini-BESTest for 105 people with PD (stage-2 and 3 on H-Y Scale) and forty-seven age-matched health controls. Mini-BESTest is comprised of 14 tasks that are designed to evaluate – anticipatory postural adjustments, reactive control of posture, sensory orientation and dynamic gait in an individual. The maximum score for the Mini-BESTest is 28 points and tasks were scored on the ordinal scale of 0 (not able to perform) to 2 (normal). Average total score for Mini-BESTest was significantly reduced in PPD when compared with healthy age-matched controls (19.0 Vs 22.8). Interestingly, PPD performed significantly worse in the sub-component of sensory orientation when compared with age-matched controls. The sub-component of Sensory orientation consists of tasks like – standing on
fixed surface (eyes open), standing on a sponge surface (eyes closed) and standing on an inclined surface with eyes closed.

King et al., 2012 (19) compared the scores of Berg Balance Scale (BBS) in PD group and age-matched healthy controls. Balance assessment was performed on twenty-three individuals with mild PD (stage 1-2 H-Y scale), twenty-three with moderate PD (stage-3-4 H-Y Scale) and forty healthy age matched controls using the BBS. Significant reduction in the BBS scores was noted between healthy controls and participants with stage 1-2 PD (55.6 vs 52.1) and between stage 1-2 PD and stage-3-4 PD (52.1 vs 40.6). Another study reported a significantly reduced Timed Up-and-Go test (TUG) performance in PPD when compared with healthy age-matched controls. During the TUG test, PPD took an average time duration of 17.3 seconds to complete the task as compared to 10.4 seconds by the healthy age-matched controls (63).

Some research studies have also associated poor performance in BBS, TUG, and Mini-BESTest with an increase in disease severity (64,65). Several studies which conducted these clinical scales on PD patients have shown significant reduction in the total scores and overall performance (66–68). The major issue of using these clinical scales is their ceiling effect. Thus BBS, TUG or Mini-BESTest are insufficient in evaluating and detecting balance impairments for the complete spectrum of PD (65,69,70). These clinical scales are mostly observational and are not ideal for assessing the dual-task components of balance functions in PPD.

Balance impairments and postural instability are often associated with higher risk of falls in PPD (71). Majority of the conventional clinical balance evaluation tests are self-perceived like
questionnaire and are performed in a very predictable environmental. Moreover, a ceiling effect for these tests is often encountered during examination of early stage PD. Sensory Organization Test (SOT) is quite reliable in evaluating subtle changes in standing balance, but it is quite expensive to operate and maintain. The sway created by the SOT is limited to the pitch plane i.e. it is unidirectional and limited to just the frontal plane direction. Modified CTSIB test is a useful substitute for the SOT because it is inexpensive and quite easy to conduct. In CTSIB, a sponge is used as a compliant surface for standing, which results in a multi-directional disturbance to the standing balance in an individual. This method can also be used to evaluate standing balance while performing a concurrent computer-based cognitive task. A pressure mat which is placed on the sponge surface is capable of recording the COP excursions, sway path length and all the critical aspects of evaluating normal as well as DT- standing balance performance (72).
2.2: Parkinsonian Gait

Parkinsonian gait is typically characterized by three independent components – gait slowness (pace and rhythm), shuffling and an increased gait variability (73). Numerous research studies have quantified spatial and temporal gait parameters in the PD population using either the GAITRite instrumented walkway, inertial sensors or video motion analysis (22,74–77).

A study Hass et al., 2012 (21) evaluated several spatiotemporal gait variables in a cohort of 310 PPD using the five-meter-long instrumented walkway system “GAITRite". Participants were divided into three groups based on their severity – Mild (less than stage 1-2, H-Y Scale), Moderate (stage-2 and 3) and severe (stage-3-4). Severe group was characterized by significantly lower gait speed and cadence in comparison with other two disease groups. Participants in the severely affected group showed a significant reduction in the base of support, stride length and swing time duration while walking when compared with the other two groups. A significantly decreased stance phase time duration and double-support phase time duration was observed in the severely affected PPD as compared to the mild and moderate PD group.

A recent study Schlachetzki et al., 2017 (79) quantified the spatiotemporal gait variables between the PD population and healthy age-matched controls using the inertial motion sensors. Similar, reduction in average stride length, gait speed, cadence and a significantly increased stride duration was observed in the PD group when compared with the normal age-matched healthy control group. Decrease in the gait speed was positively related to an increase in severity and stage of PD (H-Y Scale). Participants at stage-3 of H-Y scale exhibited an increased reduction in the gait speed when compared with participants at a very early stage of PD. The
severely affected PD group exhibited higher scores for part three of Unified Parkinson’s Disease Rating Scale (UPDRS -motor examination) which was strongly associated with reduced stride length and an increased stance phase duration.

In the PD population, mobility impairments are often exacerbated by the presence of bradykinesia, rigidity and tremors. Gait in PD is marked by a reduced velocity, short steps, shuffling and an uneven arm swing (22,74–77,79). Deficits in walking as seen in PD are often associated with reduced quality of living and increase risk of falling (80,81).
2.3: Executive cognitive functions in PD

Approximately 30 percent individuals with PD exhibit deficits in Executive Cognitive Function (ECF) (82). Inhibition, working memory and cognitive flexibility are three classifications of ECF. The inhibition domain is composed of selective attention, cognitive inhibition and self-control. PD exhibit reduced cognitive flexibility which comprises of set-shifting, mental flexibility, and creativity, Working memory as well as cognitive inhibition is also affected in PPD when compared with healthy age matched individuals (83,84). Besides balance and gait impairments several studies have associated increased risk of fall with the decline in the ECF in PPD (85,86).

A study Bezdicek et al., 2017 (87) used the Frontal Assessment Battery (FAB) to examine and compare the ECF in forty-one PPD(H-Y Scale, stage - 2 and 3) and forty-one age-matched healthy controls using the FAB clinical test. FAB comprises of tasks like – similarities, word fluency, motor series (Luria) test, conflicting instructions, go-no-go tasks etc. Scores for FAB were reduced significantly in PD group as compared to healthy age-matched controls. Furthermore, twenty-nine individuals from the PD group and twenty-seven controls underwent the resting MRI examination. MRI findings revealed a significant reduction in the activity of the pre-frontal cortex for PPD as compared to the health controls.

Several other studies have used a variety of neuropsychological tests such as- Wisconsin Card Sorting Test (WCST), Trail Making Tests (TMT), Controlled Oral Word Association Test (COWAT) and Stroop test for assessing the Executive functions in PPD (88,89). Bott et al., 2014 (90) reported an average time duration of 74.37 seconds for PD group as compared with 57.33 seconds in age matched healthy controls for completing TMT-B. Similarly, control group
performed significantly better during a one-minute Stroop task as compared to the PD group.

Milder forms of executive-cognitive dysfunction during the early stage of PD can progress to dementia in the later on stages of the condition (91). Domellof et al., 2015 (92) showed that out of forty-nine participants which cognitive decline during the early stage PD, twenty-five (51%) progressed to PD with dementia (PDD) within 5 years. Another study reported a high incidence of dementia, approximately 98.9 per 1000 person-years of observation in PPD exhibiting early cognitive decline (93).
2.4 Freezing of Gait

Freezing of gait (FOG) is defined as “absence or marked reduction of the forward progression of the feet, despite the intention to walk” (94). Freezing of Gait (FOG) is experienced by more than 44% individuals with Parkinson’s disease (95). Many studies have reported “Freezing of gait” as a critical indicator and major cause of falls in PD population.

A study Schlenstedt et al., 2016 (96) tested with freezing (n=31), non-freezers (n=27) and 22 age-matched healthy controls with Fullerton Advanced Balance (FAB) scale. The average total scores of the FAB scale, as well as the sub-tests like the functional reach task, tandem walking, eyes closed standing on a compliant surface, were significantly reduced in freezers. The severity of FOG was positively associated with the reduced scores for the FAB, functional reach task; standing on foam with eyes closed and reduced average anterior COP displacements during the limit of stability test.

Another study, Shine et al., 2013 (97) used the combination of non-immersive virtual reality (VR) task and functional MRI (fMRI) to examine the cortical and subcortical structures associated with the FOG in PPD. Ten individuals in FOG+ group and ten in FOG-, performed a task of moving through a VR corridor (first person view) while simultaneously pushing the pedals, for progressing forward in the VR environment. Paddle stop and start instructions were displayed on the screen in the form of a visual Stroop test. During the VR task, participants with FOG+ suffered motor arrests 2.7 times more than the FOG- group. Functional MRI findings revealed a significant increase in the activity of bilateral dorsolateral prefrontal cortex, posterior parietal cortex and reduced activation of the sensorimotor cortex during the freezing episodes.
Components of basal ganglia such as head of caudate, anterior thalamus, globus pallidus internus and subthalamic nuclei showed a significant reduction in the neural activity for the freezers group.

Freezing of gait is often associated with a decrease in the executive-cognitive functions especially in the domains of response inhibition and set shifting (98,99). Freezing of gait is often triggered by narrow walkway or doorways (100) low medication levels and during the dual task walking conditions (101–103).
2.5: Fall Risk of Parkinson's disease

Severe impairments in balance, gait and executive-cognitive functions are often associated with increased risk of fall in PD. More than fifty percent PPD experience falls and many of the individuals encounter multiple fall events in a single year (104–108). Falls not only leads to injuries and fractures but they also affect the psychological health of a PD patient. Fear of falling especially during the outdoor walking can lead to a significant reduction in the level of physical and mental activities (109).

A study Mak, Wong, & Pang, 2014 (110) conducted a 12-month prospective cohort study which included 144 PPD (H-Y Stage-2 and 3). All participants and their fall events were followed every month for one year. Out of 144 PPD, 42 were classified as “recurrent fallers” as they experienced more than one fall (in a year) and significantly higher scores for freezing of gait questionnaire (FOGQ). Participants classified as recurrent fallers also exhibited significantly lower scores for Activities-specific Balance Confidence (ABC), Mini-BESTest, and for Initiation-Perseveration subtest of Mattis Dementia Rating Scale (MDRS-IP) as compared with non-fallers. Multiple logistic regression analysis showed that lower scores in the ABC and MDRS-IP were highly associated with increased risk of falling in PPD. This study revealed a positive correlation between decreased executive-cognitive functions and elevated risk of fall in PPD.

Another study, Paul et al., 2014 (105) evaluated the relationship between the motor and cognitive resources and an increased risk of falling in PD population. This study recruited 205 individuals with PD (stage 1 to 4, H-Y scale) and each participant was instructed to maintain a
fall diary and record all his/her falls per month for six months. Participants were designated as fallers if they had more than one incidence of fall during those six months. All participants were evaluated with Unified Parkinson’s Disease Rating Scale (UPDRS), freezing of gait questionnaire (FOGQ), functional reach test, alternate step test and Frontal assessment battery (FAB). Standing balance performance was quantified using the sway-meter, which revealed a significantly higher COP sway in fallers group during standing on a firm surface, foam surface and tandem stance conditions when compared with non-fallers group. Fallers also reported significantly lower scores on FOGQ and pull test of the UPDRS. Ninety-one percent participants in the fallers group scored less than 17 points in FAB test.
2.6: Dual-Task gait performance in PD

As discussed earlier, a large percentage of PD population exhibit impairments to the standing balance and mobility functions. Mobility impairments are further exaggerated when an individual with PD is subjected to a concurrent cognitive task while walking (111–116). Salazar et al., 2017 (117) compared the DT interference in nineteen PPD (stage-2, H-Y Scale) and thirteen age-matched healthy individuals. All participants were instructed to perform three trials of walking on a 10-meter walkway while simultaneously performing modified vocal trail making task (TMT-B), i.e. speaking the numbers and letter in an order. As compared to the walk only trials, PD group exhibited a significant reduction of gait velocity and stride frequency during DT walking condition.

A study Stegemoller et al., 2014 (118) quantified the spatio-temporal gait parameters and cognitive performance during single and DT walking conditions in thirty-five clients with PD (Stage 1-3, H-Y scale). Participants were made to walk over the ground on a 12-meter walkway at their preferred speed of walking. Ten trials of normal walking without any cognitive task and five walking trials while performing serial three subtractions were conducted on a 12-meter walkway. Gait performance was evaluated using thirty-five retroreflective markers and video motion analysis. A significant reduction in the stride length and swing time duration were observed in PPD, additionally the stance time duration was increased during the DT-walking condition when compared with walk only condition. During the DT-walking task, all individuals showed a reduced gait velocity when compared with walk only task. Researcher’s mentioned nothing about the cognitive task performance for PPD.
Another study Fernández-Lago et al., 2015 (119) compared the dual-task performance in nineteen PPD (Stage 1-3, H-Y Scale) and 19 age-matched healthy controls. Gait performance was evaluated on an 8-meter long walkway as well as on a standard treadmill. Walking protocol included normal walking with no task (Single task or ST) and walking while performing a phenome-monitoring task (DT-walking). Each walking task was conducted for a minute, and gait performance was quantified using a video motion analysis. During the overground DT-walking task, both groups showed a relevant reduction in the gait velocity as compared to ST walking, with PD group exhibited a higher reduction in the gait velocity as compared with healthy control group. Stride frequency was significantly reduced for the PD group when compared with controls during both ST and DT walking task on the overground as well as on treadmill. During the overground walking tasks both groups exhibit a significant decrease in the average stride length during the DT as compared with ST walking. During treadmill DT-walking task, both groups showed an increase in the average stride length when compared with overground walking. PD group showed higher coefficient of variation (COV) for stride frequency on overground walking (both DT and ST) as compared with control group. During the overground walking both groups showed a significant increase in the COV of stride frequency during DT condition as compared with ST walking while treadmill walking showed no such changes. During overground walking, COV of stride length was significantly increased in PD group than the control group and during DT as compared with ST walking condition. During treadmill walking, both groups showed a significant reduction in the COV of stride length when compared with overground walking for both ST and DT walking. PPD showed a significant reduction in the cognitive performance over the treadmill as compared to the baseline (in sitting position).
Many research studies in the past, have reported similar findings for the over ground DT-walking studies in PD population. During DT-walking, patients with PD exhibit a reduced step length, stride length, stride frequency, and an increased stride to stride variability or COV. Majority of the research studies, which quantified the overground walking performance in PD, have typically reported a decrease in the walking speed during the DT-walking task when compare with the walk only (116,118,120,121).
2.7: Effect of walking speed on the gait parameters

A few research studies have highlighted the impact of gait velocity on the spatial and temporal gait parameters in PPD. Frenkel-Toledo et al., 2005 (122) examined the effect of different gait speeds over the average stride length, stride duration, swing duration as well as variability of stride duration and swing duration in PPD. Thirty-six individuals with PD (stage-2 and 3 H-Y scale) and thirty age-matched healthy controls were made to walk at their comfortable speed of walking, followed by 80%, 90% and 110% of their comfortable speed on a treadmill. Each walking task was performed for two minutes. Slower walking speed led to a significant reduction in both average stride length, average swing time and an increase in the stride duration for PD group. PD group also exhibited a significant increase in the stride length, swing time as well as a reduction in stride time during fast speed walking conditions. Similar results were obtained for the age-matched healthy control group. PD group also exhibited an increased COV for stride time was significantly during slow walking trial (80% of comfortable speed), while no other significant change in variability was observed at any other walking speed for PD.

Similarly, Cole, Sweeney, Conway, Blackmore, & Silburn, 2017 (123) quantified the spatiotemporal gait variables during various speeds of walking in PPD. Ten clients with PD (fallers i.e. known history of falls), ten clients with PD (Non-fallers i.e. no history of falls) and ten age-matched healthy controls were made to walk over treadmill at their comfortable speed, slow speed (70% of comfortable walking speed) and fast speed (130% of comfortable walking speed). Each walking task was performed for 1 minute and data was recorded with the help of two inertial sensors positioned at the occiput and tenth thoracic spinous process for each participant. Average stride length and cadence were significantly increased while the COV for
stride time was reduced with an increase in the speed of walking. These findings were similar for all the three groups.

Another study, T. Szturm et al., 2013 (124) quantified the effect of gait velocity over the temporal variables of gait, stability and cognitive performance in twenty healthy clients. Each participant was made to perform a 2-minute-long walking task at 0.7 m/s (slow speed) and 1.0 m/s (fast speed) over a standard treadmill, under walk only condition followed by walking while completing computer game based visuospatial task (DT). For assessing single task cognitive performance, each participant was made to perform the computer game-based task in normal standing condition. In-shoe pressure insoles were used to compute the gait variables, while the gaming application software was capable of recording the success rates, average response time and the movement execution time for each game event. There was a significant reduction in the average and Co-efficient of variation (COV) for step time (ST), swing time (SwT) and double support time (DS) with an increase in the walking speed. COV for ST, SW, and DS was significantly higher in DT-walking when compared with the single task walking.

Several research studies have shown the effect of walking speed over various temporal and spatial gait parameters (125–128). An increase or decrease of walking speed directly change the average and COV’s for stride time, swing time, cadence and other important gait parameters in PD population. Thus, gait speed is an important confounding variable, which influences and change other important spatiotemporal variables of gait. There is a need to control the speed of walking for accurately assessing the effect of a concurrent cognitive task over gait parameters. Furthermore, research studies which evaluated the DT performance among PPD have consistently reported a reduction of gait speed as one of their major observation (122–124,126). Majority of these studies were performed over the ground, which is incompetent in controlling
the gait speed during the walk only and DT-walking conditions.
Summary

Eighty-Seven percent PPD develop significant balance and gait impairments within three years of their diagnosis (108). Along with mobility limitations, executive-cognitive impairments are also quite common in individuals with PD (23,24,129). Dual-task conditions that require simultaneous processing of both executive-cognitive functions and sensorimotor resources poses greater problems and increase risk of falls for PPD. Individuals with stage-2 and 3 PD on H-Y scale, are able to perform the easier DT-activities, but they encounter a lot of problem when the DT- load increases (29). Several studies, which evaluated the DT-walking have shown a significant reduction in the motor as well as cognitive performance in PPD when compared with healthy age-matched controls (130).

Gait variability or stride-to-stride fluctuations are better indicators of motor control of walking than other commonly used spatial and temporal parameters like average gait speed, step time etc. (131). Gait variability gives better information about the pathological and age-related changes in gait, as well as it helps in predicting the disease severity and risk of fall (132,133). Galna, Lord, & Rochester, 2013 (133) evaluated the type of walking protocol and the number of steps needed for reliable estimation of gait variability in PPD. Results of this study computed that a continuous walking protocol yields a significantly higher reliability for gait variability as compared with the intermittent walking protocols. Minimum thirty steps are required for a reliable estimation of gait variability in PPD.

Most of the overground DT studies have GAITRite (5-meter-long instrumented walkway), 3-D Gait analysis or infrared cameras with body markers, which can only record 4-6 consecutive steps. These instruments may quantify the gait speed, but they are not reliable for
evaluating the gait variability. Moreover, the concurrent cognitive task, which is performed while walking, is limited to a few meters (distance) or few seconds (time duration).

Another major limitation in the research of dual-task walking is a lack of consistent, reliable and valid measures for evaluating the secondary cognitive task performance. The majority of the dual–task studies performed with PD population have used cognitive tasks like - Trail making tests A and B, serial subtraction by 3’s or 7’s, verbal fluency and/or auditory Stroop test (135,136). The performance of these secondary cognitive tasks is mostly graded by quantifying the response time and/or number of correct responses. Thus, analysis of these tasks fails to provide information on the broad range of visuomotor and visual-spatial resources used for completing that secondary cognitive activity. Visual-spatial processing cues, locating, tracking and navigating objects in space, are critical for maintaining safe balance and mobility behavior in an individual (124). Effective and appropriate outcome measures not only help in evaluating the dual-task performance of a participant, it also helps in formulating an effective intervention to improve the deficits (137).

Based on this information, our research group has developed a reliable and a valid Computer Game based Rehabilitation Platform (GRP) (72,138,139). This platform has a standard treadmill comprised of an instrumented pressure mapping system for computing gait parameters along with a computer gaming subsystem. The computer gaming application is specially designed to challenge the visual attention, visual search, tracking and visuospatial processing, which are important aspects of executive-cognition functions. The computer application is capable of recording the client’s response time, movement execution time, errors, movement variability for the computer gaming task by using advanced data logging analysis. A participant
can walk on a fixed speed and perform the concurrent cognitive task over this platform. Thus, GRP is capable of evaluating both physical as well as executive cognitive performance simultaneously; recording up to 30 to 60 steps in an individual.

A study T. J. Szturm et al., 2017 (138) evaluated the test-retest reliability and discriminative validity of computer game based dual task treadmill walking protocol in the healthy old age population. Twenty- five healthy individuals with age between 60 -67 years were made to perform four walking tasks (each 1 minute) over a treadmill at the speed of 0.9 m/s. Walking protocol included – walk only and walking while playing the visuomotor (VMT) tracking task as well as two visuospatial (VMG) computer gaming tasks. The instrumented pressure mapping system placed right under the treadmill belt helped in computing the gait parameters (Average and coefficient of variation). Computer gaming software generated the Coefficient of Determination (COD) based on the average and total errors for evaluating the VMT performance while success rate, average response time and average movement time were computed to evaluate the VMG performance. ICC values for most of the spatial and temporal variables of gait indicated towards a high test-retest reliability during each walking task. The visuomotor tracking and visuomotor gaming task performance measures showed moderate ICC values for all participants. Individuals exhibited a significant reduction in swing time (ST), step length (SL) while the average single support duration (SST) and COV values for ST, SL and SST were increased during the VMG task as compared to the walk only condition. Computer gaming performance revealed a significant reduction in COD for VMT-task and success rates for VMG task during the DT-walking as compared to the computer game only condition (standing).
Another study, T. Szturm et al., 2015 (72) examined the test-retest reliability and construct validity for a Computer Game Based Platform (TGP) which integrates the balance resources with executive-cognitive functions. Balance performance was evaluated for thirty healthy individuals (age more than 60 years) during 5 tasks – standing with eyes open, eyes closed, standing while doing a head tracking task followed by visuospatial computer gaming tasks, on fixed surface as well as on sponge surface. Standing balance performance was evaluated with the help of a pressure-sensing mat that captured the COP excursions during each task. Average and total residual errors were quantified for the head tracking task, while the cognitive game performance was quantified using the – average response time, movement time duration and success rates. Root mean square COP values showed high test-retest reliability for each standing task with ICC values ranging from 0.55 to 0.70. Head tracking task and cognitive game performance showed moderate to high test-retest reliability for each standing task. Standing on sponge with eyes close as well as while performing cognitive gaming task led to a relevant increase in the COP sway for all participants. Success rates for cognitive gaming task were significantly reduced for sponge standing condition as compared with fixed surface standing.

Both of these studies established the reliability and validity of computer game-based assessment tool for evaluating DT-balance and DT-walking for the healthy geriatric population. These research studies addressed and improved all the major limitations associated with the assessment of dual-task balance and walking. Strong to moderate ICC values, reduce the values of Minimal Detectable Change (MDC) and other systematic error proves the capability of the computer game based rehabilitation platform for older adults. Furthermore, no such system has
been used for evaluating the dual-task performance for PPD. Hence, there is a need to evaluate and examine the reliability and validity of Computer Game Based Rehabilitation System (CGBRS) for assessing DT-Balance and DT walking for PD population. This integrated system will help in developing safe balance and walking behaviors for PPD.
Study Purpose

This study aims to establish the psychometric properties of the Computer Game Based Rehabilitation System (CGBRS) for PPD.

The CGBRS has a standard treadmill that consists of an instrumented pressure mapping system to quantify the gait performance along with an interactive computer gaming subsystem. The CGBRS is also comprised of a standard LED monitor, which is useful for conducting numerous visuomotor and visual-spatial cognitive gaming activities while simultaneously walking on the treadmill. The computer gaming software is comprised of activities that involve tracking of a moving visual targets as well as interacting with the suitable target and ignoring the distractor. The gaming software is capable of recording a client’s performance based on the response time duration, movement execution time, success rates and movement errors using an advance data logging analysis.
Study objectives and hypothesis

Objective 1 – To evaluate the test-retest reliability of CGBRS for examining the standing balance, gait, visuomotor tracking and visuomotor gaming performance measures in PD.

- **Hypothesis 1** - Our system will exhibit moderate to good test-retest reliability for balance, gait, visuomotor tracking and visuomotor gaming activity performance measures.

Objective 2 – To evaluate the discriminant validity by examining the effect of dual-tasking over standing balance, gait, visuomotor tracking and visuomotor gaming task performance in PD.

- **Hypothesis 1** – Increased visuomotor tracking demands will significantly reduce the balance and gait performance in individuals with PD.

- **Hypothesis 2** – Increased visuomotor gaming demands will significantly reduce the balance and gait performance in individuals with PD.

- **Hypothesis 3** – Increased physical demands will significantly reduce the visuomotor tracking and visuomotor gaming task performance measures in individuals with PD.
Objective 3 - To examine the convergent validity by comparing the outcome measures of CGBRS and Unified Parkinson’s Disease Rating Scale (UPDRS)

- **Hypothesis 1** – Dual task standing balance performance measures will exhibit poor to low association with UPDRS – 3 scores (motor examination part).

- **Hypothesis 2** – Dual task gait performance measures will exhibit poor to low correlation with UPDRS – 3 scores (motor examination part).

Objective 4 - Effect of disease severity on the dual task performance in stage two and stage three participants with PD.

- **Hypothesis 1**- Increased dual task interference will lead to a significant reduction in gait performance for stage-3 PPD as compared to stage-2 individuals with PD.

- **Hypothesis 2**- Increased dual task interference will lead to a significant reduction in the VMT and VMG task performance for stage-3 PPD as compared to stage-2 individuals with PD.
Chapter 3. Methods

3.1: Sample size calculation

Sample size for this study was computed using the table 1 from Zou, 2012 (140). Thirty-five participants are required for ICC value of 0.8, assurance of 80% and CI-half width of 0.15.

3.2: Ethical Approval

Protocol for this study has been duly authorized by the Health Research Ethics Board (HREB), Research Ethics-Bannatyne, University of Manitoba (H2017:225)

3.3: Study participants

3.3.1: Inclusion criteria

- Age of participants should be between 55 to 70
- Diagnosed with idiopathic PD, defined by the UK Brain Bank criterion
- In disease stage-2 – 3 (classified by Hoehn and Yahr scale)
- Montreal cognitive assessment (MoCA) scores to be 25 or higher.
- Participants should be able to walk at least 50 meters without any assistance.
3.3.2: Exclusion criteria

- Any psychiatric co-morbidity
- Clinically diagnosed dementia or any clinically significant cognitive impairment.
- History of neurological disorder other than PD, which could affect the performance in an individual.
- Orthopedic disorders which can affect gait or balance for the participant
- Any unstable medical condition which majorly includes cardio-vascular impairments that could affect the normal walking ability of an individual.

3.3.3: Recruitment

- Participants were recruited from the summer physical therapy outpatient clinic organized by the College of Rehabilitation Sciences (University of Manitoba).
- Deer lodge Center (Movement disorder clinic) and Parkinson’s Society of Manitoba were contacted for helping us with the recruitment. Dr. Douglas Everett Hobson and all the staff of Movement disorder clinic, which allowed us to present our research study in various group meetings and PD group sessions. They also advertised and advised patients with PD to take part in our research study.

3.3.4: Study setting

All the aspects of this research study were accomplished in Room: RR345, Rehabilitation Hospital, 800 Sherbrook Ave
3.4: Equipment’s and Instruments

3.4.1: Standing Balance and Pressure mapping system

A Force Sensor Application (FSA) pressure-mapping carpet (Vista Medical Ltd. Winnipeg, Canada) was used to record the Center of foot Pressure (COP) displacements. This FSA carpet has 256 piezo-resistive sensors (16 into16) embedded in it and each sensor can record an area of 2.8 cm². This pressure mat was used to evaluate the standing balance for all the participants on a compliant (sponge) surface.

All participants were tested on either an 8-inch-thick or a 6-inch thick sponge depending on their comfort level. Sponge surface was a square with a length of 20 inches and density of 22.66 kg/m³. A wooden board with dimensions of 16 inches length and 11 inches width was also placed on the top of sponge for participants to stand.

3.4.2: Gait Evaluation

All participants were tested on a treadmill instrumented with a pressure mapping system. A T635 modal Treadmill (SportsArt Fitness Ltd. Taiwan) with the belt length of 61 inches and width of 22 inches was used for this research study. The treadmill was also equipped with front and side hand railings and an overhead harness system (non-weight bearing) to ensure safe walking conditions for every participant.

The FSA pressure mapping carpet was placed underneath the belt of the treadmill for recording the COP displacements during treadmill walking. This FSA pressure mapping carpet
has 512 piezo-resistive sensors (16 into 32) embedded in it and each sensor can record an area of 2.8 cm². FSA pressure carpet is like any conventional instrumented walkway systems like GAITRite, Zenowalkway, and GaitMat. In our system, this FSA pressure mat was carefully placed under the treadmill belt, which can successfully record the COP data for any number of steps at a constant speed, set with the help of treadmill. This data was processed and analyzed to provide the spatial and temporal gait parameters for participants with PD.

### 3.4.3: Computer gaming subsystem

A thirty-inch LG monitor screen was used to conduct the computer game based cognitive tasks for each participant.

A scoop pointer air mouse developed by Hillcrest Lab (Rockville, MD) which is similar to an optical computer mouse was attached to a helmet. Previous studies have established the utility of the Hillcrest scoop pointer mouse, as an instrument to interact with the computer cursor (138,139). All the participants were made to wear this helmet and only head rotations were used to control the cursor as well as to perform the computer game based cognitive tasks.

![Figure 1- Hillcrest scoop pointer air mouse mounted over a helmet](image-url)
3.4.4: Computer application based cognitive tasks

A custom interactive computer gaming software "Neuro-function evaluation" (NFE) was used to perform the computer game-based assessment task. The computer application tasks require participants to perform only the head rotational movement for performing the assessment.

**Visuomotor Tracking (VMT) task** – This gaming task evaluated the visuomotor tracking (VMT) abilities in individuals with PD. The goal of the VMT task was to align the two objects that appeared on the computer monitor. One object was a computer controlled yellow colored circle (target) moving horizontally on the screen. The other object is a rectangular paddle, which is controlled manually via the head rotation movement of the participant. The goal of the VMT task was to align the paddle with the circle (target) and try to position the two objects over each other. It is a closed loop smooth pursuit cognitive task where participants tracked a computer-controlled target (circle) with the help of head rotations. Each participant performed this task for 30 seconds during sitting as well as standing over the sponge and for 45 seconds during the treadmill walking.

Computer controlled circle (target) moved horizontally at a frequency of 0.5 hertz and amplitude of 0.60 i.e. covering 60% width of the monitor. During the treadmill walking, the amplitude was reduced to 50 % of the screen width. The NFE software is capable of recording the trajectory of the paddle (rectangle) with respect to the target movement at a sampling rate of 100 Hz. Logged data files are created at the end of each VMT task and used to quantify the task performance.
**Visuomotor gaming (VMG) task** - This gaming task evaluated the executive- cognitive abilities especially the planning, data processing and visuospatial abilities of the participants with PD. The procedure of wearing the helmet and performing the head rotations remains the same. The objective of this gaming task was to move the paddle, which is located at the bottom of the screen to catch the dropping target object. For each VMG task – participants encountered two objects falling from the top of the monitor screen. All Participants must catch the soccer balls (target) and avoid the dotted sphere (distractor).

Based on the difficulty two types of VMG tasks were performed -

**Visuomotor Gaming Task Easy (VMG-1)** – Target plus one distractor falling in a straight trajectory. The game background was kept solid grey, and objects on the screen i.e. target and distractor was easily distinguishable.

**Visuomotor Gaming Task difficult (VMG-2)** – Target plus one distractor falling in a diagonal trajectory. The game background forced an optical illusion (blue water droplet) and raised the visual difficulty for the participants. The dimension of target and distractors were kept similar and their speed was increased to raise the task difficulty.

Both the objects appeared simultaneously on-screen at an interval of 1.5 seconds. Each participant performed the VMG task for 45 seconds during sitting as well as standing on sponge, and for 60 seconds while walking over the treadmill. Mouse cursor sensitivity was reduced for the treadmill dual task. Our gaming application software is capable to record the temporal variables and overall gaming performance for each participant. At a sampling rate of 100 hertz, data files were created and used to quantify the VMG task performance.
All participants completed the Unified Parkinson’s Disease Rating Scale and Montreal Cognitive assessment questionnaire for examining their physical as well as neurological performance.

3.4.5: Other scales and tests for screening and evaluation

- **Montreal Cognitive Assessment (MoCA)**- was used as a screening test for detecting any significant executive-cognitive impairments in participants with PD. MoCA test various cognitive functions like short-term memory, visuospatial ability, trail-making, phonemic fluency, attention, working memory etc. MoCA is administered in ten minutes (approximately) and total score for this test is thirty points.

- **Unified Parkinson’s disease Rating Scale (UPDRS)** - is regarded as a gold standard rating scale, which helps to evaluate the disability and impairment in Parkinson's disease. It is a 5-point rating scale (from 0 to 4) in which zero describes absence or least severity while four describes the highest severity. Increase in severity is denoted with higher scores. Scores were computed for - Mentation, Behavior, and Mood (Part 1), Activities of Daily Living (Part 2) and the Motor Examination (Part 3). Scores of all the three sections were added and computed as the "Final UPDRS scores" for our clinical trial. UPDRS has shown excellent test-retest reliability in PD population. Siderowf et al. (2002) (141) has reported an Intraclass Correlation Coefficient (ICC) values of 0.92 for UPDRS scale in total, with ICC values of 0.85 and 0.90 for activities of daily living and motor examination part respectively. Many other studies have also shown similar results.
(60,142). Combining the total points for part 1, part 2 and part 3, UPDRS total score can range from zero to 176.
3.5: Testing Protocol

All the testing was conducted at the clinical research laboratory of Dr. Tony Szturm RR345, Rehabilitation Hospital 800 Sherbrook Ave. Winnipeg Manitoba. All clients were tested on two separate occasions, which were kept at least one week apart from each other. All the participants performed the computer game-based tasks within a viewing distance of nearly one meter from the LG monitor screen.

Test day - 1 –

This session lasted for approximately 90 minutes. Firstly, all participants were provided with a brief explanation about the purpose of this study and the computer game-based rehabilitation system. In order to examine if the subject suits the inclusion criterion, he/she was made to walk 50 meters without any assistance in a hallway. Cognitive performance of each participant was evaluated using the Montreal Cognitive Assessment (MOCA) tool. All participants were provided with a brief demonstration of the computer gaming tasks and were asked to sign the informed consent form.

After signing the consent form, participants sat comfortably on s chair and the helmet with hillcrest mouse was placed on their head. All participants were made play few trials of both VMT and VMG tasks in order to get accustomed with working of mouse and computer gaming tasks. Participants were asked if they are comfortable in starting the research study protocol.

Sitting position – A cushioned wooden chair with back support but no armrest was placed on the treadmill. Participants sat comfortably and then performed the VMT task for 30 seconds. After that, both VMG task i.e. VMG-1 and VMG-2 task were performed for 45 seconds
in comfortable sitting position. Files of all the four trials were saved in the computer system hard drive.

**Standing on the compliant surface** – A sponge pad was kept on the treadmill and all participants were instructed to stand on the sponge. On basis of their comfort levels participant were made to stand over either a 6-inch-thick or an eight-inch-thick sponge pad. A wooden board was also kept over the sponge surface and FSA pressure mat was then placed on the wooden board. Participants were made to stand safely over the sponge surface holding the side or\and front railings of the treadmill. Participants were gradually instructed to stand on the sponge surface without any support and maintain their balance. A clinical researcher was always standing behind the participant during all the sponge standing testing procedures. Following tasks were then conducted for each participant -

1. **Eyes open standing or stand only (SO)** – COP displacements of all the participants was recorded during normal standing over the sponge with eyes open for 30 seconds each. All participants were instructed to hold the side or the front railing for support whenever they experience a loss of balance or instability during the task.

2. **DT-standing on the sponge surface** - Participants were asked to perform the computer game based cognitive task while standing on the sponge surface without hands support. VMT or head tracking task was played in horizontal direction for 30 seconds each. Both VMG-1 and VMG-2 were also conducted for 45 seconds each while standing on the sponge.

3. **Walking on the treadmill** – Prior to this task, all participants were made to wear a safety jacket, which was then attached to the safety harness, for preventing falls or any unlikely event during treadmill walking.
All participants were walked on treadmill at their comfortable speed for 5-10 minutes before the assessments. Walking trials were performed for making participants comfortable and acclimatize with the treadmill walking before the initiation of the actual testing protocol. Firstly, participants walked while holding on to the safety railings and then they were gradually instructed to walk without any hand support. Computer game based cognitive tasks were administered only when participants got comfortable and gained his/her confidence on the treadmill.

All participants walked in their comfortable walking speed on the treadmill during the testing procedures. Normal walking without any secondary cognitive task was recorded using the pressure mat and the motion monitor units for 60 seconds. Thus, spatiotemporal variables were quantified during the comfortable walking or walk only (WO) condition. After that, the participant randomly performed VMT task for 45 seconds or any of the VMG task for one minute while walking on the treadmill.

For every participant, the order of the sitting protocol, standing on the sponge and walking over treadmill protocol was randomized. Even the pattern of VMT and VMG task was randomized to every client in order to reduce the order effect and predictability factor. However, the same pattern of the protocol was followed in the next session for testing the psychometric properties of the Computer Game Based Rehabilitation System.

After the testing was completed, participants rested accordingly. After resting, Unified Parkinson’s Disease Rating Scale or the UPDRS was conducted. Part 1 and 3 of the UPDRS were completed after the protocol while all participants completed the activities of daily living (Part 2) section of UPDRS at home and returned it back in the next session.
Test day 2 –

The second session was conducted after at least one week from the first session and lasted for about 45 – 60 minutes.

1. Exactly the same protocol in the same order as of session 1 was executed using the computer game-based rehabilitation system (CGBRS).

2. Activities of daily living sections (part-2) of the UPDRS was also reviewed for each participant.

![Figure 2 – Testing protocol](image-url)
### 3.6: Data analysis

#### 3.4.1: Balance Assessment

Center of foot pressure (COP) displacements was recorded in the anterior-posterior (AP) and medial-lateral (ML) directions using the FSA mat. Root mean square (RMS) amplitude measure for COP excursions in AP and ML directions was used to quantify the standing balance for each participant. A higher RMS value is indicative of high COP displacements and reduced standing balance in the participants (138,143).

![FSA Mat recording the Foot pressure and COP while standing](image1)

![COP Excursions during Standing](image2)

**Figure 3 – Standing balance evaluation and raw COP signals**
3.4.2: Gait Assessment

Participants walked on a standard treadmill (Sports Art Fitness Ltd, Mukilteo, Washington), while a force sensing pressure mapping carpet (Vista Medicals Ltd., Winnipeg) was placed right under the treadmill belt, for recording the center of foot pressure (COP). Gait data was analyzed from approximately 30 steps per leg during – normal walking (Single task) and walking while performing the VMG and VMT task (DT- walking).

Foot contact pressure data was used to quantify the center of foot Pressure (COP) displacement in AP as well as ML directions. COP data was analysed using the custom-built MATLAB scripts (Math Work, Natick, MA) to extract the spatiotemporal variables of gait for the participants with PD.

Spatiotemporal variables for gait were classified into four important domains -

1. For “Pace domain” – Average step length for each leg
2. For “Rhythm domain” – Average stride time and average swing time duration.
3. For “Variability domain” – Coefficient of Variation (COV) of step length, COV of stride time and swing time
4. Variability for the foot-step drifting on treadmill belt in A-P as well as M-L direction were also computed

Many studies have used these spatiotemporal variables for evaluating the gait and mobility in participants with PD. Studies performed on the PD population have reported average and COV values of these gait variables for evaluating the test-retest reliability and convergent validity (136).
Figure 4 – Gait assessment and raw signals for COP during walking
3.4.3: Visuomotor tracking (VMT) task performance measures

At the end of each VMT or head-tracking task, “NFE” software showed a graph depicting the participant performance. A predetermined “sine wave function” graph for the computer-controlled target (sphere) waveform is plotted for the “reference”. The head rotation trajectories for the participants (in red) was computed based on their performance and positioned over the “reference” sine wave function (138,139).

1. The total residual error was quantified based on the variation between the movement trajectories of the computer-controlled target and the rectangular paddle movements directed by the participant.
2. COV amplitude variation was computed for over 15 cycles during sitting as well as sponge surface standing and for over 22 cycles during the treadmill walking. Amplitude variation denotes the movement consistency during the VMT event. First two cycles for every VMT event were not quantified in order to align the participant head motion with the moving target.

![Figure 5 – Visuomotor task and performance evaluation](image)
3.4.4: Visuomotor cognitive gaming (VMG) performance measures

At the end of every VMG task, the “NFE software” generated a participant performance report. Neuro-functional evaluation (NFE) software is capable of recording all the movement traces of any direction and amplitude. In the present research study, all the participants are performing the VMG task in horizontal positions i.e. moving right to left and vice-versa (138,139).

Visuomotor gaming task performance was evaluated by computing following parameters

- Average response time – Average time duration between appearances of the target on the screen until the initiation of the paddle movement.
- Success rate – percentage of successful targets (soccer balls) caught by the participant in both the directions (Left and right).
- Movement variance – Variability between the movements was computed for each direction (Left and right)

![Figure 6 – VMG-1 (left) and VMG-2(center) task and performance evaluation](image-url)
Chapter 4. Statistical analysis

1. **Objective 1** – To evaluate the test-retest reliability of CGBRS for examining the standing balance, gait, visuomotor tracking and visuomotor gaming performance measures in PD.

*Hypothesis 1* – *Our system will exhibit moderate to good test-retest reliability for balance, gait, VMT and VMG task performance measures*

- For **relative reliability** – Intra-class correlation coefficients (ICC) were computed.

- Koo., 2016 (144) gave following cut-offs for interpreting ICC values:
  
  a) ICC < 0.5 – poor reliability
  
  b) ICC between 0.5 to 0.75 - moderate reliability
  
  c) ICC between 0.75 to 0.9 – good reliability
  
  d) ICC > 0.9 – excellent reliability

- For **absolute reliability** – Minimal detectable change (MDC) was computed using following formula to calculate MDC for each outcome measures,

\[ \text{MDC (95% CI)} = 1.96 \times \text{SEm} \times \sqrt{2} \]

Where SEm denoted the standard error of measurement, which is derived by multiplying standard deviation from the test -1 with \( \sqrt{1-\text{ICC}} \). Additionally, MDC% (MDC as percentage of group mean) will be calculated by dividing the MDC with Group mean of Test-1.
• **Paired t-test** was performed to observe any systematic biases between both testing days.

2. **Objective 2** – To evaluate the discriminant validity and examine the effect of dual-tasking over standing balance, gait, visuomotor tracking and visuomotor gaming task performance in PD.

   a. **Paired T-test was completed for computing**

   • *Hypothesis 1* – *Increased visuomotor tracking demands will significantly reduce balance and gait performance in individuals with PD.*

     o **Independent variable** – Visuomotor Gaming (VMT) task performance

     o **Dependent variable** – Balance outcome measures and spatio-temporal gait parameters

   b. **One-way repeated measure ANOVA was completed for computing**

     • *Hypothesis 2* – *Increased visuomotor gaming demands will significantly reduce balance and gait performance in individuals with PD.*

     o **Independent variable** – Visuomotor gaming (VMG) task performance

     o **Levels** – Easy VMG-1 task and Difficult VMG-2 task

     o **Dependent variable** – Balance outcome measures and spatio-temporal gait parameters
• **Hypothesis 3**– Increased physical demands will significantly reduce the visuomotor tracking and visuomotor gaming task performance in individuals with PD.

  o **Independent variable** – Physical demands

  o **Levels** - sitting, standing on sponge (balance) and walking over treadmill

  o **Dependent variables** – Visuomotor tracking and visuomotor gaming task performance measures.

3. **Objective 3**- Examine the convergent validity by comparing the outcome measures of CGBRS and Unified Parkinson’s Disease Rating Scale (UPDRS)

  *Spearman correlation* was completed to compute the association between the balance and gait performance during dual task conditions with the total score of UPDRS-3.

4. **Objective 4** – Effect of disease severity on the dual task performance in stage two and stage three participants with PD.

  Mixed ANOVA was completed for computing –

  • **Hypothesis 1** - *Increased dual task interference will significantly reduce gait performance for stage-3 PPD as compared to stage-2 individuals with PD.*

    o **Independent variable** – Severity of disease (Stage-2 vs Stage 3)

    o **Dependent variable** - Spatial and temporal gait parameters.

    o **Between group factor** – Stage of PD (Stage-2 and Stage 3)
Evaluation of a Computer Game Based Rehabilitation System for assessment of balance and gait impairments in individuals with Parkinson’s disease.

- **Within group factors** –
  
  a) Walk alone vs walking while performing VMT task
  
  b) Walk alone vs walking while performing VMG-1 task
  
  c) Walk alone vs walking while performing VMG-2 task

- **Interaction term** – Cognitive task and PD severity

*Hypothesis 2* - *Increased dual task interference will significantly reduce the VMT and VMG task performance for stage-3 PPD as compared to stage-2 PD participants.*

- **Independent variable** – Severity of disease (Stage-2 vs Stage 3)

- **Dependent variable** – VMT, VMG-1 and VMG-2 gaming task performance

- **Between group factor** – Stage of PD (Stage-2 vs Stage 3)

- **Within group** – Sitting vs walking

- **Interaction term** – Physical condition vs severity of PD

SPSS software for windows, version 22.0 (SPSS Inc., Chicago, IL, USA) was used to perform all the statistical analysis in the study.
Chapter 5. Results

5.1: Demographics

Table 1 presents the demographic data for all the twenty-six participants that took part in this research study. Out of 26 participants, seventeen were males, nine were females with mean age of 65 ± 6.31 years, and all were clinically diagnosed with PD. Thirteen participants were stage-2 and thirteen participants were stage-3, according to the H-Y scale. Average values for UPDRS (Total) were 35.84 and UPDRS (Motor part) was 25.92. Mean value for MoCA was 28.96 and each participant was able to walk 50 meters (unassisted) thus fulfilling our inclusions criterion.

Table 1 - Demographic data for all the research study participants

<table>
<thead>
<tr>
<th>Total Participants</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ± SD) in years</td>
<td>64.92 ± 6.21</td>
</tr>
<tr>
<td>Male/ Female (%)</td>
<td>17 (65.4%)/ 9 (34.6%)</td>
</tr>
<tr>
<td>Time since diagnosis (years)</td>
<td>5.60 ± 4.44</td>
</tr>
<tr>
<td>Hoehn and Yahr scale</td>
<td></td>
</tr>
<tr>
<td>Participants at Stage-2 (%)</td>
<td>13 (50%)</td>
</tr>
<tr>
<td>Participants at Stage-3 (%)</td>
<td>13 (50%)</td>
</tr>
<tr>
<td>UPDRS Total (mean ± SD)</td>
<td>36.11 ± 12.31</td>
</tr>
<tr>
<td>UPDRS Motor (mean ± SD)</td>
<td>25.88 ± 8.79</td>
</tr>
<tr>
<td>MoCA (mean ± SD)</td>
<td>28.92 ± 1.07</td>
</tr>
</tbody>
</table>

(MoCA – Montreal Cognitive Assessment, UPDRS – Unified Parkinson’s Disease Rating Scale)
5.2: Test-retest reliability

5.2.1: Standing Balance outcome measures

Table 2 show the results of mean and SD for both test days, ICC values (95% CI), MDC values, MDC% values and t–statistics for the COP displacements in both A-P and M-L directions. Stand only (Single task) task and standing while performing VMG-1 task showed moderate to good test-retest reliability, with 95% CI of ICC values ranging from 0.5 to 0.9 for RMS-COP measures (both A-P and M-L). The RMS-COP values during VMG-2 and VMT DT-standing task showed poor to good test-retest reliability, with 95% CI of ICC values ranging from as low as 0 to 0.85. Majority of MDC% values ranged from 60% to 85% for RMS values in both A-P and M-L directions. Paired student t-test revealed no significant difference between test 1 and test 2 group mean performance.

Table 2 – Test-retest reliability for Balance COP-AP and COP-ML excursion during standing on the sponge tasks. This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics

<table>
<thead>
<tr>
<th>Condition</th>
<th>Test1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC Value (95% CI)</th>
<th>MDC (% of mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root Mean Square (COP-AP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S0</td>
<td>1.15 (0.59)</td>
<td>1.11 (0.65)</td>
<td>0.80 (0.53 – 0.90)</td>
<td>0.73 (63.4)</td>
</tr>
</tbody>
</table>
### Root Mean Square (COP-ML)

<table>
<thead>
<tr>
<th></th>
<th>COP-AP</th>
<th>COP-ML</th>
<th>ICC</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S0</strong></td>
<td>1.13 (0.72)</td>
<td>1.30 (0.86)</td>
<td>0.8 (0.56 – 0.91)</td>
<td>0.89 (78.76)</td>
</tr>
<tr>
<td><strong>S_VMG-1</strong></td>
<td>2.29 (1.43)</td>
<td>2.16 (1.66)</td>
<td>0.65 (0.10 – 0.86)</td>
<td>1.83 (79.34)</td>
</tr>
<tr>
<td><strong>S_VMG-2</strong></td>
<td>2.48 (1.21)</td>
<td>2.40 (1.40)</td>
<td>0.62 (0.01 – 0.85)</td>
<td>1.83 (73.79)</td>
</tr>
<tr>
<td><strong>S-VMT</strong></td>
<td>2.43 (0.95)</td>
<td>2.24 (1.05)</td>
<td>0.60 (0.05 – 0.83)</td>
<td>1.66 (68.31)</td>
</tr>
</tbody>
</table>

**Significant p <0.05**

(COP-AP – Center of foot pressure excursion in Antero-posterior direction, COP-ML – Center of foot pressure excursion in Medio-lateral direction, S0-stand only, S_VM-T-Standing while performing the VMT task, S_VM-G-Standing while performing the VMG-1 task, S_VM-G-2 - Standing while performing the VMG-2 task, ICC-Intraclass Correlation, MDC – Minimal Detectable Change, CI-Confidence Interval)
5.2.2: Spatial and temporal Gait outcome measures

Table 3 and 4 presents the mean and SD for both test days, ICC values (95% CI), MDC values, MDC% values and t–statistics for Avg. (Avg.) and coefficient of variations (COV) of spatial and temporal gait outcome measures respectively. Walk only condition demonstrated good to excellent with 95% CI values ranging from 0.8 to 0.96 for all Avg. SL, SrT and SwT. Walking while performing VMG-1, VMG-2 and VMT task also showed good to excellent test-retest reliability, with 95% CI values ranging from 0.8 to 0.95 for all average gait parameters. Majority of the MDC% values ranged from 18 to 35 for Avg. SL and 10 – 16 percent for Avg. SrT and SwT during all four walking tasks. Paired student t-test revealed no significant difference between test 1 and test 2 group mean performance.

Table 3 - Test-retest reliability for Average Spatial and Temporal gait outcome measures during treadmill walking tasks. This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics

<table>
<thead>
<tr>
<th>Gait Measures</th>
<th>Condition</th>
<th>Test 1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC Value (95% CI)</th>
<th>MDC (%) of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. SL (cm)</td>
<td>WO</td>
<td>45.93 (18.03)</td>
<td>44.82 (17.85)</td>
<td>0.92 (0.84 - 0.96)</td>
<td>13.80 (30.04)</td>
</tr>
<tr>
<td></td>
<td>W_VMG-1</td>
<td>41.70 (18.39)</td>
<td>43.98 (15.75)</td>
<td>0.93 (0.85 - 0.97)</td>
<td>13.17 (31.59)</td>
</tr>
</tbody>
</table>
As presented in table 4, during all the four walking task conditions, moderate to excellent test-retest reliability (95% CI values – 0.6 to 0.9) was observed for COV values of SL, SrT and SwT. The majority of the drift parameters (both in A-P and M-L directions) exhibited poor to
good test-retest reliability with 95% CI values of ICC ranging from 0.2 to 0.8 for all four walking tasks. The majority of the MDC% values ranged from 50 to 90% for COV SL, and between 65 to 90 percent for COV SrT and COV SwT. Paired student t-test revealed no significant difference between test 1 and test 2-group mean performance. Minimal Detectable Change (MDC) percentage of mean values ranged from 50 to 60% for COV drift (A-P). Furthermore, COV drift in ML directions showed very high MDC% values, with walk only task reaching up to 98%. Paired student t-test revealed no significant difference between test 1 and test 2 group mean performance.

Table 4 - Test-retest reliability for COV Spatial and Temporal gait outcome measures during treadmill walking tasks. This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics

<table>
<thead>
<tr>
<th>Gait measures</th>
<th>Condition</th>
<th>Test 1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC Value (95% CI)</th>
<th>MDC (% of mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV SL (%)</td>
<td>WO</td>
<td>26.20 (20.23)</td>
<td>24.63 (23.09)</td>
<td>0.81 (0.58 – 0.91)</td>
<td>24.42 (93.20)</td>
</tr>
<tr>
<td></td>
<td>W_VMG-1</td>
<td>39.25 (26.15)</td>
<td>34.31 (24.91)</td>
<td>0.84 (0.65 – 0.92)</td>
<td>28.97 (73.80)</td>
</tr>
<tr>
<td></td>
<td>W-VMG-2</td>
<td>36.47 (21.45)</td>
<td>35.82 (21.28)</td>
<td>0.90 (0.77 – 0.95)</td>
<td>18.78 (51.50)</td>
</tr>
<tr>
<td></td>
<td>W_VMT</td>
<td>36.07 (26.50)</td>
<td>34 (23.38)</td>
<td>0.87 (0.71 – 0.94)</td>
<td>23.21 (64.34)</td>
</tr>
<tr>
<td>COV SrT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(%)</td>
<td>WO</td>
<td>W_VMG-1</td>
<td>W_VMG-2</td>
<td>W_VMT</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>------</td>
<td>---------</td>
<td>---------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8.31 (8.52)</td>
<td>9.70 (7.77)</td>
<td>8.77 (6.59)</td>
<td>9.29 (8.56)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8.54 (9.43)</td>
<td>9.02 (9.10)</td>
<td>9.57 (9.00)</td>
<td>9.72 (9.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.92 (0.82 – 0.96)</td>
<td>0.90 (0.77 – 0.96)</td>
<td>0.90 (0.78 – 0.96)</td>
<td>0.92 (0.82 – 0.96)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.67 (80)</td>
<td>6.80 (70)</td>
<td>5.77 (65.79)</td>
<td>6.70 (72.80)</td>
<td></td>
</tr>
<tr>
<td>COV SwT (%)</td>
<td>WO</td>
<td>W_VMG-1</td>
<td>W_VMG-2</td>
<td>W_VMT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.93 (11.28)</td>
<td>12.93 (10.56)</td>
<td>12.52 (9.65)</td>
<td>13.02 (12.04)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.07 (12.62)</td>
<td>12.62 (13)</td>
<td>12.74 (11.27)</td>
<td>13.03 (13.06)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.89 (0.76 – 0.95)</td>
<td>0.86 (0.69 – 0.94)</td>
<td>0.84 (0.64 – 0.92)</td>
<td>0.91 (0.80 – 0.96)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.88 (90.40)</td>
<td>9.25 (71.50)</td>
<td>10.35 (82.66)</td>
<td>10.00 (76.80)</td>
<td></td>
</tr>
<tr>
<td>COV Drift A-P (%)</td>
<td>WO</td>
<td>W_VMG-1</td>
<td>W_VMG-2</td>
<td>W_VMT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.60 (4.94)</td>
<td>18.42 (9.78)</td>
<td>13.84 (5.05)</td>
<td>13.15 (5.34)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.34 (3.93)</td>
<td>16.30 (6.75)</td>
<td>14.40 (5.12)</td>
<td>12.24 (4.37)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.79 (0.53 – 0.95)</td>
<td>0.64 (0.15 – 0.85)</td>
<td>0.66 (0.24 - 0.84)</td>
<td>0.67 (0.27 - 0.85)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.12 (52.60)</td>
<td>16.02 (86.90)</td>
<td>7.66 (55.30)</td>
<td>8.10 (61.50)</td>
<td></td>
</tr>
<tr>
<td>M-L (%)</td>
<td>WO</td>
<td>W_VMG-1</td>
<td>W_VMG-2</td>
<td>W_VMT</td>
<td></td>
</tr>
<tr>
<td>--------</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.92 (9.70)</td>
<td>17.74 (9.45)</td>
<td>18.56 (13.44)</td>
<td>16.28 (8.48)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.37 (9.82)</td>
<td>17.43 (11.17)</td>
<td>17.06 (12.43)</td>
<td>17.67 (9.10)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.63 (0.17-0.83)</td>
<td>0.75 (0.44-0.88)</td>
<td>0.74 (0.43-0.88)</td>
<td>0.67 (0.27-0.85)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.65 (98)</td>
<td>13.08 (73.70)</td>
<td>16.64 (89.60)</td>
<td>12.86 (78.90)</td>
<td></td>
</tr>
</tbody>
</table>

Significant p <0.05

(COV - Coefficient of variability, SL - Step length, SrT - Stride Time, SwT - Swing Time, WO - Walk only, W_VMT - Walking while performing the VMT task, W_VMG-2 – Walking while performing the VMG-1 task, W_VMG-2 - Walking while performing the VMG-2 task, ICC - Intraclass Correlation, MDC – Minimal Detectable Change, CI - Confidence Interval)
5.2.3: Visuomotor tracking (VMT) task performance measures

Table 5 presents the mean (SD) for both test days, ICC values (95% CI), MDC values, MDC% values and t statistics for VMT task performance measures during – sitting, standing on sponge and walking on a treadmill. Moderate to excellent test-retest reliability was demonstrated by the total residual errors, with 95% CI of ICC values ranging from 0.6 to 0.9 during – sitting, sponge standing as well as walking task conditions. The COV amplitude variance showed poor to moderate test-retest reliability during all the three test conditions. The majority of the MDC% values were reported below 36 % for total residual errors and below 80 % for COV amplitude variance. Paired student t-test revealed no significant difference between test 1 and test 2 group mean performance.

Table 5. – Test-retest reliability for Visuomotor (VMT) task performance during sitting, standing on sponge and walking on treadmill. This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics

<table>
<thead>
<tr>
<th>Outcome Variables</th>
<th>Condition</th>
<th>Test1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC Value (95% CI)</th>
<th>MDC (% of mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Residual Error (%)</td>
<td>Sitting</td>
<td>11.27 (3.58)</td>
<td>10.95 (4.14)</td>
<td>0.88 (0.74 – 0.95)</td>
<td>3.43 (30.43)</td>
</tr>
<tr>
<td></td>
<td>Standing on sponge</td>
<td>12.61 (3.78)</td>
<td>12.02 (3.50)</td>
<td>0.81 (0.58 – 0.91)</td>
<td>4.56 (36.16)</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>14.60 (4.19)</td>
<td>13.36 (3.69)</td>
<td>0.76 (0.48 – 0.89)</td>
<td>5.68</td>
</tr>
<tr>
<td>COV Amplitude variance (%)</td>
<td>Sitting</td>
<td>Standing on sponge</td>
<td>Walking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------</td>
<td>--------------------</td>
<td>---------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.8 (8.75)</td>
<td>20.56 (8.54)</td>
<td>0.50 (0 – 0.78)</td>
<td>17.14 (80.20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22.04 (8.81)</td>
<td>21.10 (6.95)</td>
<td>0.60 (0 – 0.82)</td>
<td>15.43 (70.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29.85 (9.50)</td>
<td>30.28 (11.14)</td>
<td>0.40 (0 – 0.73)</td>
<td>20.38 (68.2)</td>
<td></td>
</tr>
</tbody>
</table>

Significant p < 0.05

(ICC-Intraclass Correlation, MDC – Minimal Detectable Change, CI-Confidence Interval, COV-Coefficient of variability)
5.2.4: Visuomotor gaming (VMG) task performance

Table 6a presents the mean (SD) for both test days, ICC values (95% CI), MDC values, MDC% values and t statistics for VMG-1 task performance measures during – sitting, standing on sponge and walking on a treadmill. Moderate to good test-retest reliability was demonstrated by average response times and success rates, with 95% CI of ICC values ranging from 0.5 to 0.8 for standing on sponge and walking task conditions. Both average response times and success rates showed poor to moderate test-retest reliability during sitting or single task conditions. The movement variance exhibited poor to good test-retest reliability for all the three tasks – sitting, standing on sponge and walking. The majority of MDC% values were reported below 20 percent for Avg. response time and success rate, while movement variance was below 33 percent for VMG-1 task.

Table 6b presents the mean (SD) for both test days, ICC values (95% CI), MDC values, MDC% values and t statistics for VMG -2 task performance during – sitting, standing on sponge and walking on a treadmill. Poor to moderate test-retest reliability was observed for average response times and movement variance, with 95% CI of ICC values ranging from 0 to 0.7 for all the three tasks – sitting, standing on sponge and walking. Success rate measure showed moderate to excellent test-retest reliability with 95% CI values of ICC ranging from 0.6 to 0.9 during all the three tasks. The majority of MDC% values for Avg. response time and success rate were less than 20 percent for the VMG-2 task. For movement variance, MDC% values ranged from as low as 20 percent in sitting to 40 percent while walking. Paired student t-test revealed no significant difference between group mean performances on both test days.
Table 6a. – Test-retest reliability for visuomotor game (Easy) task performance (VMG-1) during sitting, standing on sponge and walking on treadmill). This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics

<table>
<thead>
<tr>
<th>Outcome Variables</th>
<th>Condition</th>
<th>Test 1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC Value (95% CI)</th>
<th>MDC (% of mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Response Time (s)</td>
<td>Sitting</td>
<td>0.61 (0.06)</td>
<td>0.58 (0.06)</td>
<td>0.50 (0 – 0.77)</td>
<td>0.12 (19.6)</td>
</tr>
<tr>
<td></td>
<td>Standing on sponge</td>
<td>0.59 (0.08)</td>
<td>0.56 (0.08)</td>
<td>0.76 (0.46 – 0.89)</td>
<td>0.10 (16.90)</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>0.62 (0.07)</td>
<td>0.62 (0.07)</td>
<td>0.76 (0.46 – 0.89)</td>
<td>0.10 (16.12)</td>
</tr>
<tr>
<td>Success Rate (%)</td>
<td>Sitting</td>
<td>92.27 (9.35)</td>
<td>92.46 (13.43)</td>
<td>0.68 (0.26 – 0.85)</td>
<td>14.18 (15.36)</td>
</tr>
<tr>
<td></td>
<td>Standing on sponge</td>
<td>89.90 (12.10)</td>
<td>92.79 (11.47)</td>
<td>0.88 (0.72 – 0.95)</td>
<td>10.59 (11.77)</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>77.51 (16.85)</td>
<td>83.18 (18.40)</td>
<td>0.85 (0.63 – 0.93)</td>
<td>14.75 (19.02)</td>
</tr>
<tr>
<td>Movement Variance (%)</td>
<td>Sitting</td>
<td>15.72 (3.18)</td>
<td>16.05 (3.32)</td>
<td>0.63 (0 – 0.85)</td>
<td>5.21 (33.14)</td>
</tr>
<tr>
<td></td>
<td>Standing on sponge</td>
<td>17.4</td>
<td>15.90</td>
<td>0.60 (0 – –)</td>
<td>5.57</td>
</tr>
</tbody>
</table>
Table 6b. – Test-retest Reliability for visuomotor game (difficult) task performance (VMG-2) during sitting, standing on sponge and walking on treadmill. This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics.

<table>
<thead>
<tr>
<th>Outcome Variables</th>
<th>Condition</th>
<th>Test 1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC Value (95% CI)</th>
<th>MDC (% of mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. Response Time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sitting</td>
<td>0.63 (0.07)</td>
<td>0.62 (0.06)</td>
<td>0.85 (0.68 – 0.93)</td>
<td>0.07 (11.06)</td>
</tr>
<tr>
<td></td>
<td>Standing on sponge</td>
<td>0.64 (0.05)</td>
<td>0.58 (0.06)</td>
<td>0.62 (0 – 0.85)</td>
<td>0.09 (13.71)</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>0.69 (0.06)</td>
<td>0.66 (0.06)</td>
<td>0.40 (0 – 0.71)</td>
<td>0.14 (20.28)</td>
</tr>
<tr>
<td></td>
<td>Success Rate (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sitting</td>
<td>82.89 (15.38)</td>
<td>86.72 (14.16)</td>
<td>0.85 (0.65 – 0.93)</td>
<td>16.49 (19.89)</td>
</tr>
<tr>
<td></td>
<td>Standing on sponge</td>
<td>77.65 (16.11)</td>
<td>86.89 (13.76)</td>
<td>0.77 (0.3 – 0.91)</td>
<td>19.95 (25.70)</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>73.37 (15.87)</td>
<td>72.46 (19.18)</td>
<td>0.89 (0.77 – 0.95)</td>
<td>14.58 (19.87)</td>
</tr>
</tbody>
</table>

Significant p <0.05

(ICC-Intraclass Correlation, MDC – Minimal Detectable Change, CI-Confidence Interval)
## Movement Variance (%)

<table>
<thead>
<tr>
<th>Movement</th>
<th>Sitting</th>
<th>Standing on sponge</th>
<th>Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement Variance</td>
<td>18.11 (2.57)</td>
<td>20.21 (4.02)</td>
<td>21.99 (4.46)</td>
</tr>
<tr>
<td>ICC-Intraclass Correlation</td>
<td>18.79 (3.62)</td>
<td>18.90 (3.18)</td>
<td>22.12 (4.19)</td>
</tr>
<tr>
<td>MDC-Minimal Detectable Change</td>
<td>0.40 (0 – 0.72)</td>
<td>0.40 (0.37 – 0.70)</td>
<td>0.85 (0.67 – 0.93)</td>
</tr>
<tr>
<td>CI-Confidence Interval</td>
<td>5.51 (30.42)</td>
<td>8.62 (42.65)</td>
<td>4.78 (21.73)</td>
</tr>
</tbody>
</table>

**Significant p <0.05**

(ICC-Intraclass Correlation, MDC – Minimal Detectable Change, CI-Confidence Interval)
5.2.5: Increased values of MDC and subsequently MDC as percent of group mean

Based on severity of PD participants were divided into stage-2 (mild) and stage-3 (moderate) using the H-Y scale. ICC and MDC values were quantified for COV SL and drift in M-L directions during WO, W_VMG-1 and W_VMG-2. Table 7 and 8 shows the individual mean (SD), ICC, MDC and MDC% values for stage-2 and stage-3 individuals with PD, respectively.

Table 7 – Test-retest reliability of COV SL and drifts – ML for stage-2 participants with PD during treadmill walking tasks. This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics

<table>
<thead>
<tr>
<th>Gait measures</th>
<th>Condition</th>
<th>Test1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC values</th>
<th>MDC (% of mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV SL (%)</td>
<td>WO</td>
<td>13.61 (6.9)</td>
<td>13.70 (6.9)</td>
<td>0.75 (0.5 – 0.87)</td>
<td>9.40 (69)</td>
</tr>
<tr>
<td></td>
<td>W_VMG-1</td>
<td>24.20 (17.8)</td>
<td>22.70 (14.8)</td>
<td>0.90 (0.5-0.95)</td>
<td>15.50 (64)</td>
</tr>
<tr>
<td></td>
<td>W_VMG--2</td>
<td>23.60 (13.30)</td>
<td>24.80 (13.0)</td>
<td>0.95 (0.84-0.98)</td>
<td>8.23 (35)</td>
</tr>
<tr>
<td>COV Drift ML(%)</td>
<td>WO</td>
<td>10 (7.40)</td>
<td>11.36 (22.20)</td>
<td>0.80 (0.5 – 0.87)</td>
<td>9 (90)</td>
</tr>
<tr>
<td></td>
<td>W_VMG-1</td>
<td>16.10 (9.62)</td>
<td>15.54 (12.90)</td>
<td>0.92 (0.72 – 0.97)</td>
<td>7.50 (47)</td>
</tr>
<tr>
<td></td>
<td>W_VMG--2</td>
<td>13.60 (10.40)</td>
<td>16.90 (15.80)</td>
<td>0.92 (0.79 – 0.93)</td>
<td>8.10 (60)</td>
</tr>
</tbody>
</table>
Significant p <0.05
(COV SL – Variability in Step length, COV Drift ML- Variability of drift in Medio-lateral direction, ICC- Intraclass Correlation, MDC – Minimal Detectable Change, CI-Confidence Interval)

Table 8 - Test retest Reliability of COV SL and drifts – ML for stage-3 participants with PD during treadmill walking tasks. This table demonstrates the Mean (SD) for test 1 and 2, ICC values (95% CI), MDC (% of mean) and t-statistics

<table>
<thead>
<tr>
<th>Gait measures</th>
<th>Condition</th>
<th>Test 1 Mean (SD)</th>
<th>Test 2 Mean (SD)</th>
<th>ICC values</th>
<th>MDC (% of mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV SL (%)</td>
<td>WO</td>
<td>36.45 (20.01)</td>
<td>30.17 (20.43)</td>
<td>0.65 (0.4 – 0.87)</td>
<td>32.70 (90)</td>
</tr>
<tr>
<td></td>
<td>W_VMG-1</td>
<td>52.20 (27.70)</td>
<td>40.82 (27.40)</td>
<td>0.80 (0.54 – 0.94)</td>
<td>34.31 (66)</td>
</tr>
<tr>
<td></td>
<td>W_VMG--2</td>
<td>45.20 (21.30)</td>
<td>41.70 (20.35)</td>
<td>0.80 (0.54 – 0.94)</td>
<td>26.40 (58)</td>
</tr>
<tr>
<td>COV Drift ML(%)</td>
<td>WO</td>
<td>19 (9.90)</td>
<td>16.76 (7.90)</td>
<td>0.70 (0.33-0.83)</td>
<td>15.02 (80)</td>
</tr>
<tr>
<td></td>
<td>W_VMG-1</td>
<td>18.80 (10.04)</td>
<td>18.12 (9.50)</td>
<td>0.80 (0.59 – 0.88)</td>
<td>12.43 (66)</td>
</tr>
<tr>
<td></td>
<td>W_VMG--2</td>
<td>21.55 (11.70)</td>
<td>18.07 (9.40)</td>
<td>0.90 (0.62 – 0.98)</td>
<td>10.24 (47)</td>
</tr>
</tbody>
</table>

Significant p <0.05
(COV SL – Variability in Step length, COV Drift ML- Variability of drift in Medio-lateral direction, ICC- Intraclass Correlation, MDC – Minimal Detectable Change, CI-Confidence Interval)
5.3: Discriminant validity

5.3.1: Dual task interference on Standing Balance

Figure 7– Bar graphs displaying the group means and standard error of means (SEM) for RMS COP displacement in both AP as well as M-L direction for all standing balance tasks. The bars (left to right) represents the balance performance during stand only (SO) and standing while performing the VMT, VMG-1 and VMG-2 task conditions.
Table 9 presents the results of paired t-test that compared standing balance performance during single and VMT DT-standing condition. There was a significant increase in RMS COP displacements during VMT dual-task condition as compared to the stand only condition. This was the case for both A-P and M-L directions.

Table 9 – Comparison between stand only and standing while performing VMT task

<table>
<thead>
<tr>
<th>Balance Measures</th>
<th>SO vs S_VMT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS (COP-AP)</strong></td>
<td>t-statistics, p-value</td>
</tr>
<tr>
<td></td>
<td>-4.82, 0.001</td>
</tr>
<tr>
<td><strong>RMS (COP-ML)</strong></td>
<td>-7.83, 0.001</td>
</tr>
</tbody>
</table>

n = 26, Significant p <0.05

(RMS- Root mean square, COP-AP – Center of foot pressure excursion in Anterio-posterior direction, COP-ML – Center of foot pressure excursion in medio-lateral direction, SO-stand only, S_VMT-Standing while performing the VMT task, n = sample size)

Table 10 presents the results of one-way repeated measure ANOVA for comparing the standing balance performance during stand only and standing while performing the VMG-1 and VMG-2 dual task standing condition. Significant with-in group difference was observed between SO, S_VMG-1 and S_VMG-2 task for RMS amplitude values in AP as well as ML directions. Pairwise comparison revealed a significant increase in RMS values between stand only condition and dual task (VMG-1 and VMG-2) standing conditions in both directions (A-P as well as M-L).
Table 10 – Comparison between stand only and standing while performing VMG-1 and VMG-2

<table>
<thead>
<tr>
<th>Outcome Variables</th>
<th>Anova Tests</th>
<th>SO vs S_VMG-1</th>
<th>SO vs S_VMG-2</th>
<th>S_VMG-1 vs S_VMG-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f - value</td>
<td>p - value</td>
<td>t-statistics ,p-value</td>
<td>t-statistics ,p-value</td>
</tr>
<tr>
<td>RMS (COP-AP)</td>
<td>27.06</td>
<td>0.001</td>
<td>-4.38, 0.001</td>
<td>-4.4, 0.001</td>
</tr>
<tr>
<td>RMS (COP-ML)</td>
<td>10.12</td>
<td>0.001</td>
<td>-4.78, 0.001</td>
<td>-6.19, 0.001</td>
</tr>
</tbody>
</table>

Significant p <0.05, n = 26

(RMS- Root mean square, COP-AP – Center of foot pressure excursion in Anterio-posterior direction, COP-ML – Center of foot pressure excursion in medio-lateral direction, SO-stand only, S_VMG-1 Standing while performing the VMG-1 task, S_VMG-2 - Standing while performing the VMG-2 task, n = sample size)
5.3.2: Dual task interference on gait performance

Figure 8– Bar graphs displaying the group means and standard error of means (SEM) for spatio-temporal gait parameters during all the treadmill-walking tasks. The bars (left to right) represents the gait performance during walk only (WO) and walking while performing the VMT, VMG-1 and VMG-2 task condition.
Table 11 presents the results of paired sample t-test for comparing gait performance between walk alone (single task) and walking while performing the VMT task (DT-walking). Average SL, SrT and SwT showed significant reduction during the DT-walking (W_VMT) as compared to single task (WO). During DT-walking (W_VMT), all participants showed increased values for variability in SL and SwT as compared to the walk only task.

*Table 11 – Comparison between walk only and walking while performing VMT task*

<table>
<thead>
<tr>
<th>Gait Outcome Measures</th>
<th>WO vs W_VMT</th>
<th>t-statistics, p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. SL (cm)</td>
<td>1.98, 0.07</td>
<td></td>
</tr>
<tr>
<td>Avg. SrT (s)</td>
<td>3.44, 0.003</td>
<td></td>
</tr>
<tr>
<td>Avg. SwT (s)</td>
<td>2.91, 0.008</td>
<td></td>
</tr>
<tr>
<td>COV SL (%)</td>
<td>-3.22, 0.001</td>
<td></td>
</tr>
<tr>
<td>COV SrT (%)</td>
<td>-1.47, 0.16</td>
<td></td>
</tr>
<tr>
<td>COV SwT (%)</td>
<td>-1.84, 0.03</td>
<td></td>
</tr>
<tr>
<td>COV Drift ML (%)</td>
<td>-1.64, 0.11</td>
<td></td>
</tr>
<tr>
<td>COV Drift AP (%)</td>
<td>-1.98, 0.06</td>
<td></td>
</tr>
</tbody>
</table>

n=26, Significant p <0.05

(Avg. – Average, COV- Coefficient of variability, SL-Step length, SrT- Stride Time, SwT- Swing Time, WO-Walk only, W_VMT-Walking while performing the VMT task, s- seconds, cm- centimeter, n – sample size)
Table 12 presents the results of one-way repeated measure ANOVA for comparing the gait performance during walk only (single task) and walking while performing VMG-1 and VMG-2. Significant with-in group difference was observed between WO, W_VMG-1 and W_VMG-2 task for majority of the spatio-temporal gait variables. Pairwise comparison revealed a significant reduction of Avg. SrT and SwT during VMG dual task walking (both VMG-1 and VMG-2 tasks) as compared to the walk only task. During both VMG DT-walking, participants exhibited significant increase in the values of COV SL, SwT and both drifts parameters as compared to the walk only task. Furthermore, drift in A-P directions were significantly higher for the W_VMG-1 task as compared to the VMG-2 DT-walking.

Table 12 – Comparison between walk only and walking while performing VMG-1 and VMG-2 task.

<table>
<thead>
<tr>
<th>Gait Outcome Measures</th>
<th>Anova Tests (With-in group)</th>
<th>WO vs W_VMG-1</th>
<th>WO vs W_VMG-2</th>
<th>W_VMG-1 vs W_VMG-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f-value</td>
<td>p-value</td>
<td>t-statistics, p-value</td>
<td>t-statistics, p-value</td>
</tr>
<tr>
<td>Avg. SL (cm)</td>
<td>4.683</td>
<td>0.024</td>
<td>2.03, 0.06</td>
<td>1.55, 0.14</td>
</tr>
<tr>
<td>Avg. SrT (s)</td>
<td>8.86</td>
<td>0.005</td>
<td>2.76, 0.01</td>
<td>3.29, 0.004</td>
</tr>
<tr>
<td>Avg. SwT (s)</td>
<td>6.335</td>
<td>0.014</td>
<td>2.54, 0.02</td>
<td>2.60, 0.02</td>
</tr>
<tr>
<td>COV SL (%)</td>
<td>16.59</td>
<td>0.001</td>
<td>-4.72, 0.001</td>
<td>-5.21, 0.001</td>
</tr>
<tr>
<td>COV SrT (%)</td>
<td>1.43</td>
<td>0.10</td>
<td>-1.34, 0.20</td>
<td>-0.33, 0.74</td>
</tr>
<tr>
<td></td>
<td>COV SwT (%)</td>
<td>0.03</td>
<td>-2.19, 0.04</td>
<td>-1.27, 0.06</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>COV Drift ML (%)</td>
<td>4.25</td>
<td>0.03</td>
<td>-2.38, 0.02</td>
<td>-2.11, 0.03</td>
</tr>
<tr>
<td>COV Drift AP (%)</td>
<td>11.42</td>
<td>0.001</td>
<td>-3.99, 0.001</td>
<td>-2.34, 0.04</td>
</tr>
</tbody>
</table>

n=26, Significant p <0.05

(Avg. – Average, COV- Coefficient of variability, SL-Step length, SrT- Stride Time, SwT- Swing Time, WO- Walk only, W_VMG-2 – Walking while performing the VMG-1 task, W_VMG-2 -Walking while performing the VMG-2 task, s- seconds, cm- centimeter, n=sample size)
5.3.3: Dual task interference on the VMT task performance

Figure 9 – Bar graphs displaying the group means and standard error of means (SEM) for Visuomotor task performance during single and dual task conditions. The bar (left to right) represents the VMT task performance during sitting, standing on sponge and walking on the treadmill.

Table 13 presents the results of one-way repeated measure ANOVA for comparing the VMT task performance during the single task (sitting), standing on sponge surface (DT-standing balance) and while walking on a treadmill (DT-walking). Significant increase in the total residual error was observed for both DT-standing balance and DT-walking as compared to the sitting (single task). Furthermore, total residual error values were significantly higher during the DT-walking as compared to the DT-standing balance condition. COV amplitude variance or movement variations were significantly higher for DT-walking and DT-standing as compared to the sitting task. Also, the, DT-walking showed higher movement variation for the VMT task when compared with DT-standing balance condition.
Table 13 – Comparison of VMT task performance during sitting, standing on sponge and walking tasks.

<table>
<thead>
<tr>
<th>Outcome Variables</th>
<th>Anova Tests (With-in group)</th>
<th>Sitting Vs Sponge standing</th>
<th>Sitting vs Walking</th>
<th>Sponge standing Vs Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f - value</td>
<td>p - value</td>
<td>t-statistics, p-value</td>
<td>t-statistics, p-value</td>
</tr>
<tr>
<td>Total Residual Error (%)</td>
<td>10.63</td>
<td>0.001</td>
<td>-2.28, 0.03</td>
<td>-4.73, 0.001</td>
</tr>
<tr>
<td>COV Amplitude variance (%)</td>
<td>10.23</td>
<td>0.001</td>
<td>-0.55, 0.58</td>
<td>-3.73, 0.001</td>
</tr>
</tbody>
</table>

n=26, Significant p <0.05

(COV – Coefficient of variance, n – sample size)
5.3.4: Dual task interference during the VMG task performance

Figure 9- Bar graphs displaying the group means and standard error of means (SEM) for Visuospatial gaming task performance during single and dual task conditions. The bars (left to right) represent the VMG task performance during sitting, standing on sponge and walking on the treadmill. In addition, the left row shows the VMG-1 (easy) task, while right row presents the VMG-2 (difficult) task performance.
Table 14 presents the results of one-way repeated measures ANOVA for comparing the VMG task performance during – single (sitting) and dual task (standing on sponge, walking on treadmill) conditions. During VMG-1 DT-walking, participants showed a significant increase in Avg. response time (RT) and movement variation when compared with sitting (single task) as well as while standing on sponge (DT-standing balance) task. Success rates were significantly reduced during VMG-1 DT-walking as compared to sitting and DT-standing balance. Furthermore, participants exhibited no difference in the VMG-1 task performance when single task (sitting) was compared with DT-standing balance condition.

During VMG-2 DT-walking task, all participants showed a significant increase in Avg. RT and movement variance when compared to both single task (sitting) and DT-standing balance. Success rates were significantly reduced during DT-walking as compared to the other two tasks i.e. sitting and standing on sponge. In addition, all participants showed significant reduction in success rates and increased movement variance during DT-standing balance as compared to the sitting task.
Table 14 – Comparison of VMG task (VMG-1 as well as VMG-2) performance during sitting, standing on sponge and walking tasks.

<table>
<thead>
<tr>
<th>Outcome Variables</th>
<th>Anova Tests (With-in group)</th>
<th>Sitting Vs Sponge St.</th>
<th>Sitting vs Walking</th>
<th>Sponge St. Vs Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f - value</td>
<td>p - value</td>
<td>t-statistics, p-value</td>
<td>t-statistics, p-value</td>
</tr>
<tr>
<td>Average RT – VMG-1</td>
<td>3.55</td>
<td>0.04</td>
<td>1.59, 0.12</td>
<td>-1.08, 0.29</td>
</tr>
<tr>
<td>Average RT – VMG-2</td>
<td>7.06</td>
<td>0.004</td>
<td>-0.54, 0.59</td>
<td>-3.00, 0.006</td>
</tr>
<tr>
<td>Success Rate – VMG-1</td>
<td>13.17</td>
<td>0.001</td>
<td>0.92, 0.37</td>
<td>4.04, 0.001</td>
</tr>
<tr>
<td>Success Rate – VMG-2</td>
<td>13.32</td>
<td>0.001</td>
<td>2.85, 0.009</td>
<td>5.47, 0.001</td>
</tr>
<tr>
<td>MovVar – VMG-1</td>
<td>10.63</td>
<td>0.001</td>
<td>-1.93, 0.06</td>
<td>-4.00, 0.001</td>
</tr>
<tr>
<td>MovVar – VMG-2</td>
<td>13.11</td>
<td>0.001</td>
<td>-2.81, 0.009</td>
<td>-5.14, 0.001</td>
</tr>
</tbody>
</table>

Significant p <0.05

(RT-Response time duration, MovVar – movement variance, VMG- Visuomotor gaming task, St. - Standing)
5.4: Convergent Validity

The correlation analysis was performed between the DT-standing balance measures and UPDRS-3 total scores. No values for Spearman correlation coefficient (rho) showed any significant association between the COP-displacement during various DT-standing balance conditions and UPDRS-3 total score in individuals with PD.

Similar results were obtained while associating the spatio-temporal gait parameters during Dt-walking conditions and total scores of UPDRS-3. These findings revealed a very poor association between the Dual task performance measures and scores of UPDRS-3 (motor examination part).
5.5: Effect of disease severity on DT-performance

5.5.1: Effect of increased dual – task interference on gait performance for stage-2 and stage-3 (H-Y Scale) individuals with PD

![Graphs showing gait performance](image)

*Figure 10 – line graphs displaying the group means and standard errors of means (SEM) for Avg. SL, SrT as well as Swt (top to down) in stage-2 and stage-3 PPD. Gait performance was evaluated during walk only (single task) and walking while performing VMT, VMG-1 and VMG-2 (left to right panel). Square marked lines display the performance for stage-2 participants while triangle marked lines display the stage-3 PPD.*
Figure 11 – Line graphs displaying the group means and standard errors of means (SEM) of COV SL, SrT, Swt as well as drifts (top to down) in stage-2 and stage-3 PPD. Gait performance was evaluated during walk only (single task) and walking while performing VMT, VMG-1 and VMG-2 (left to right panel). Square marked lines display the performance for stage-2 participants while triangle marked lines display the stage-3 PPD.
Table 15 presents the results of mixed model repeated measure ANOVA for comparing the gait performance between stage-2 and stage-3 participants during single and VMT DT-walking. As evident in figure 10 and 11, during walk only task, stage-3 participants walked with smaller step lengths and increased COV values for SL, SrT, SwT and drifts as compared to stage-2 PPD. Significant main effect was observed between walk only and VMT DT walking task (with-in group effect) for Avg. SrT, SwT, and COV SL as well as COV SwT gait outcome measures. Significant between group differences was observed for Avg. SL, COV SL, SrT, SwT and drifts in M-L direction. There was no significant interaction effect (PD severity and task condition) on any of the spatio-temporal gait variable.

Table 15 – Summary for the main effects of PD severity (stage-2 vs stage-3) and cognitive task conditions (WO vs W_VMT) on the gait performance.

<table>
<thead>
<tr>
<th>Gait Outcome measures</th>
<th>With-in Group (Cognitive Task)</th>
<th>Between Group (Stage of PD)</th>
<th>Interaction (Cognitive Task*Stage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F, p-value</td>
<td>F, p-value</td>
<td>F, p-value</td>
</tr>
<tr>
<td>Avg. SL (cm)</td>
<td>3.79, 0.07</td>
<td>20.48, 0.001</td>
<td>0.33, 0.57</td>
</tr>
<tr>
<td>Avg. SrT (s)</td>
<td>11.34, 0.003</td>
<td>0.82, 0.37</td>
<td>0.001, 0.99</td>
</tr>
<tr>
<td>Avg. SwT (s)</td>
<td>8.13, 0.008</td>
<td>0.56, 0.46</td>
<td>0.09, 0.76</td>
</tr>
<tr>
<td>COV SL (%)</td>
<td>19.76, 0.001</td>
<td>12.60, 0.02</td>
<td>2.77, 0.11</td>
</tr>
</tbody>
</table>
Table 16 presents the results of mixed model repeated measure ANOVA for comparing the gait performance between stage-2 and stage-3 participants during walk only and VMG-1 DT-walking. As shown in figure 10 and 11, during the walk only task, stage-3 PPD walked with much smaller step length and exhibited high COV values for SL and SwT as compared to stage-2 participants. Significant main effect between the walk only and VMG-1 DT-walking (with-in group effect) was observed for all gait parameters except Avg. SL and COV SrT. Significant between group difference was observed for Avg. SL, COV SL, and COV between stage-3 and stage-2 PPD.

Significant interaction effect (PD Severity and task condition) was observed for the COV in SwT and drifts in M-L direction. Participants with stage-2 PD exhibited higher variability in swing time and M-L drifts during VMG-1 DT-walking as compared with walk only task. While participants in stage-3 showed no significant change for COV SwT as well as M-L drifts between WO and VMG-1 DT-walking.
Table 16—Summary for the main effect of PD severity (stage-2 vs stage-3) and cognitive task condition (WO vs W_VMG-1) on the gait performance.

<table>
<thead>
<tr>
<th>Gait Outcome measures</th>
<th>With-in Group (Cognitive Task)</th>
<th>Between Group (Stage of PD)</th>
<th>Interaction (Cognitive Task*Stage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F, p-value, $\eta^2$</td>
<td>F, p-value, $\eta^2$</td>
<td>F, p-value, $\eta^2$</td>
</tr>
<tr>
<td>Avg. SL (cm)</td>
<td>4.02, 0.06</td>
<td>19.394, 0.001</td>
<td>0.31, 0.58</td>
</tr>
<tr>
<td>Avg. SrT (s)</td>
<td>7.33, 0.012</td>
<td>0.71, 0.40</td>
<td>0.02, 0.88</td>
</tr>
<tr>
<td>Avg. SwT (s)</td>
<td>6.24, 0.02</td>
<td>0.51, 0.48</td>
<td>0.13, 0.73</td>
</tr>
<tr>
<td>COV SL (%)</td>
<td>21.55, 0.001</td>
<td>11.58, 0.003</td>
<td>0.83, 0.37</td>
</tr>
<tr>
<td>COV SrT (%)</td>
<td>2.46, 0.20</td>
<td>3.20, 0.09</td>
<td>3.23, 0.09</td>
</tr>
<tr>
<td>COV SwT (%)</td>
<td>7.27, 0.04</td>
<td>7.91, 0.01</td>
<td>5.05, 0.04</td>
</tr>
<tr>
<td>COV Drift ML (%)</td>
<td>5.85, 0.02</td>
<td>3.82, 0.07</td>
<td>6.53, 0.02</td>
</tr>
<tr>
<td>COV Drift AP (%)</td>
<td>15.60, 0.001</td>
<td>0.99, 0.33</td>
<td>2.38, 0.14</td>
</tr>
</tbody>
</table>

Significant p <0.05

(COV- Coefficient of variability, SL-Step length, SrT- Stride Time, SwT- Swing Time, WO-Walk only, W_VMG-1-Walking while performing the VMG easy task, cm – centimeters, s- seconds)
Table 17 presents the results of mixed model repeated measure ANOVA for comparing the gait performance between stage-2 and stage-3 participants during walk only and VMG-2 DT-walking. As depicted in figure 10 and 11, during WO task, stage-3 participants walked with significantly reduced step lengths and exhibited higher COV values for SL, SwT and M-L drift as compared to the stage-2 participants. Majority of the gait parameters except Avg. SL, COV SrT and COV SwT, showed significant main effect between walk only and VMG-2 DT-walking (with-in group effect). Significant between group differences were observed for Avg. SL, COV SL, SrT, SwT and M-L drifts between stage-2 and stage-3 PPD.

Significant interaction effect (PD severity and task load) was observed for COV SwT. Post-hoc analysis showed that stage-2 PPD exhibited significant increase in COV of swing time during VMG-2 DT-walking as compared to the WO task. While participants in stage-3 showed no such change for COV SwT between WO and VMG-2 DT walking.
Table 17 – Summary for the main effect of PD severity (stage-2 vs stage-3) and cognitive task condition (WO vs W_VMG-2) on the gait performance.

<table>
<thead>
<tr>
<th>Gait Outcome measures</th>
<th>With-in Group (Cognitive Task)</th>
<th>Between Group (Stage of PD)</th>
<th>Interaction (Cognitive Task*Stage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$, $p$- value</td>
<td>$F$, $p$- value</td>
<td>$F$, $p$- value</td>
</tr>
<tr>
<td>Average SL (cm)</td>
<td>2.41, 0.14</td>
<td>19.65, 0.001</td>
<td>1.17, 0.29</td>
</tr>
<tr>
<td>Average SrT (s)</td>
<td>10.44, 0.004</td>
<td>0.86, 0.36</td>
<td>0.003, 0.95</td>
</tr>
<tr>
<td>Average SwT (s)</td>
<td>6.51, 0.02</td>
<td>0.93, 0.34</td>
<td>0.001, 0.90</td>
</tr>
<tr>
<td>COV SL (%)</td>
<td>15.71, 0.001</td>
<td>12.56, 0.002</td>
<td>0.06, 0.81</td>
</tr>
<tr>
<td>COV SrT (%)</td>
<td>0.37, 0.74</td>
<td>4.10, 0.06</td>
<td>3.13, 0.09</td>
</tr>
<tr>
<td>COV SwT (%)</td>
<td>2.91, 0.06</td>
<td>7.37, 0.01</td>
<td>8.43, 0.008</td>
</tr>
<tr>
<td>COV Drift ML (%)</td>
<td>5.01, 0.03</td>
<td>6.52, 0.02</td>
<td>0.53, 0.47</td>
</tr>
<tr>
<td>COV Drift AP (%)</td>
<td>4.62, 0.04</td>
<td>0.25, 0.62</td>
<td>0.88, 0.36</td>
</tr>
</tbody>
</table>

Significant p <0.05

(COV- Coefficient of variability, SL-Step length, SrT- Stride Time, SwT- Swing Time, WO-Walk only, W_VMG-2-Walking while performing the VMG difficult task, cm – centimeters, s- seconds)
5.5: Effect of increased DT-interference on Visuomotor tracking and Visuomotor gaming task performance measures for stage-2 and 3 PD

5.5.1: Effect of DT-walking task on visuomotor (VMT) task performance on stage-2 and stage-3 PPD

Figure 12 – Line graphs displaying the group means and standard errors of means (SEM) for visuomotor tracking task performance in stage-2 and stage-3 PPD. VMT task performance was evaluated in sitting (single task) and walking (dual-task) condition. Square marked lines display the performance for stage-2 participants while triangle marked lines display the stage-3 PPD.

Table 18 presents the results of mixed modal repeated measure ANOVA for comparing the VMT task performance between stage-2 and stage-3 PPD, performed during sitting (single task) and walking (DT) conditions. More evident from the figure 12, at DT-walking condition stage-3 PPD exhibited higher errors and movement variance than stage-2 PPD. A significant within-group effect was observed between sitting and DT-walking for VMT task performance.
No significant interaction effect (PD severity and physical task) was observed for any of the VMT task outcome measure.

*Table 18 – Summary for the main effect of PD severity (stage-2 vs stage-3) and physical task condition (Sitting vs walking) on the VMT task performance*

<table>
<thead>
<tr>
<th>Cognitive Performance Measures</th>
<th>With-in Group (Physical Task)</th>
<th>Between Group (Stage of PD)</th>
<th>Interaction (Physical Task*Stage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>F, p</em>-value</td>
<td><em>F, p</em>-value</td>
<td><em>F, p</em>-value</td>
</tr>
<tr>
<td>Total Residual error</td>
<td>26.44, 0.001</td>
<td>16.81, 0.001</td>
<td>1.60, 0.22</td>
</tr>
<tr>
<td>COV Amplitude variance</td>
<td>14.55, 0.001</td>
<td>4.01, 0.05</td>
<td>2.13, 0.15</td>
</tr>
</tbody>
</table>

Significant p <0.05

*(VMT- visuomotor tracking task)*
5.5.2: Effect of DT-walking on visuo-motor gaming (VMG) performance for stage-2 and stage-3 PPD

Figure 13 – Line graphs displaying the group means and standard errors of means (SEM) for visuomotor gaming task performance measures in stage-2 and stage-3 PPD. Both VMG- (left panel) and VMG-2 (right panel) task performance was evaluated in sitting (single task) and walking (dual-task) condition. Square marked lines display the performance for stage-2 participants while triangle marked lines display the stage-3 PPD.
Table 19 presents the results of mixed model repeated measure ANOVA for comparing the VMG task performance (both VMG-1 as well as VMG-2) between stage-2 and stage-3 participants, performed during sitting and DT-walking conditions. Majority of the VMG-1 and VMG-2 task performance measures showed significant with-in group effect between sitting and DT-walking condition. There was no significant between-group effect and interaction effect (PD severity and physical task) on any of the VMG performance measure.

Table 19 – Summary for the main effect of PD severity (stage-2 vs stage-3) and physical task condition (Sitting vs walking) on the VMG task performance

<table>
<thead>
<tr>
<th>Cognitive Performance Measures</th>
<th>With-in Group (Physical Task)</th>
<th>Between Group (Stage of PD)</th>
<th>Interaction (Physical Task*Stage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$, $p$-value</td>
<td>$F$, $p$-value</td>
<td>$F$, $p$-value</td>
</tr>
<tr>
<td>Average RT – VMG-1</td>
<td>2.67, 0.12</td>
<td>2.64, 0.12</td>
<td>1.82, 0.19</td>
</tr>
<tr>
<td>Average RT – VMG-2</td>
<td>8.33, 0.009</td>
<td>0.70, 0.41</td>
<td>2.97, 0.10</td>
</tr>
<tr>
<td>Success Rate – VMG-1</td>
<td>20.97, 0.001</td>
<td>3.60, 0.07</td>
<td>2.87, 0.10</td>
</tr>
<tr>
<td>Success Rate – VMG-2</td>
<td>28.80, 0.001</td>
<td>3.66, 0.07</td>
<td>0.03, 0.86</td>
</tr>
<tr>
<td>MovVar VMG-1</td>
<td>22.51, 0.001</td>
<td>0.88, 0.36</td>
<td>0.18, 0.68</td>
</tr>
<tr>
<td>MovVar VMG-2</td>
<td>22.21, 0.001</td>
<td>0.68, 0.42</td>
<td>0.06, 0.81</td>
</tr>
</tbody>
</table>
Significant $p < 0.05$

*(VMG-1 - Easy visuomotor gaming task, VMG-2 – Difficult visuomotor gaming task, RT- response time, MovVar – movement variance)*
Chapter 6. Discussion

6.1: Test-retest reliability

Overall, with a few exceptions, the Computer Game Based Rehabilitation System (CGBRS) showed moderate to good test-retest reliability for the majority of the standing balance, gait, visuomotor tracking as well as visuomotor gaming performance measures, under both single and dual task condition. Poor test-retest reliability was observed for the measures of COP displacements during DT standing conditions and drift measures during walking. Poor test-retest reliability was also demonstrated by measures of amplitude variance during VMT and movement variance during VMG task, especially during sitting and sponge standing task.

The test-retest reliability for the COP displacement measures was much higher during stand only task as compared to the DT-standing balance condition. This was in line with the findings of Swanenburg et al., 2008 (145) which also reported high ICC values for COP displacements during stand only task as compared to DT-standing balance condition. But notably, standing balance was only examined on a firm surface for healthy old-age individuals. This reduction in ICC due to increased cognitive loading was limited to the standing balance measures and was not observed in spatio-temporal gait parameters.

Majority of the spatio-temporal gait parameters except for the COV drift measures (A-P and M-L directions) exhibited moderate to good test-retest reliability during both walk only and DT-walking conditions. Moderate to good test-retest reliability was observed for the majority of visuomotor tracking (VMT) task and visuomotor gaming (VMG) task measures under all
physical conditions such as sitting, standing on the sponge and during treadmill walking. These findings are consistent with the results of Strouwen et al., 2016 (146) which examined test-retest reliability for average gait parameters and cognitive task performance measures during over-ground DT-walking in individuals with PD. All participants walked on a GAITRite instrumented walkway while performing backward-digit counting and auditory Stroop test for a period of 5 seconds (as the length of GAITRite is only 5 meters). Average gait parameters like stride length, stride time, gait speed showed good test-retest reliability during walk only and DT-walking conditions. The cognitive performance measures such as reactions times and total errors demonstrated moderate test-retest reliability during walk only and DT-walking conditions. However, the distance walked by the participants on GAITRite was only restricted to 5 to 6 steps and the duration of the cognitive task was further restricted to 5 seconds. In the present study, treadmill-based platform provides continuous DT-walking protocol with an ability to compute reliable gait variability measures for more than 30 repetitive steps (single minute task). The present research study also established moderate to high ICC values for variability in step length, stride time, swing time and drift measures and even for the cognitive performance measures during walk only and DT-walking conditions in PD. Gait variability measures are often associated with gait stability and automaticity (147,148). Few studies have also observed a strong association between increased gait variability and falls (149,150).

The majority of the average spatio-temporal gait parameters demonstrated high absolute reliability with MDC% values ranging from 10 to 30 percent. Strouwen et al., 2016 (146) observed MDC% values ranging from 10 to 20 percent for average gait parameters during DT-walking which are in line with our results. On the other hand, COV gait parameters especially the drift measures demonstrated a poor absolute reliability with MDC% values ranging from 50
to 90 percent. The majority of the VMT and VMG task outcome measures showed moderate relative reliability but good absolute reliability with MDC% values ranging from 10 to 40 percent. Strouwen et al., 2016 (146) also reported MDC% values for cognitive measures during DT-walking activity, ranging from 20 to 60 percent. The present study reported lower values of MDC%, thus improving the absolute reliability for the cognitive performance during DT-walking conditions in PD participants.

The majority of the values for COP-excursions during DT-standing balance conditions exhibited poor absolute reliability, with MDC% values ranging from 60 to 85 percent. Few of the gait parameters such as COV step length, swing time and drifts (both in A-P and M-L) also demonstrated a lower absolute reliability. Minimal detectable change is defined as the least amount of change required for a measure which denotes a real change and not due to the virtue of a measurement error (151). As reported in Steffen., 2008 (151), research sample in the present study represented a wider range of PD severity, with equal numbers for both stage-2 (mild) and stage-3 (moderate) participants. As presented in table 7 and 8, dividing participants into stage-2 and stage-3 decreased the standard deviations for the gait parameters, which subsequently reduced the MDC values for each task. For example, overall group MDC% values of drift in ML direction during walking while performing VMG-2 task was 94.70 percent. After dividing participants based on PD severity, MDC% values for ML-drifts substantially reduced to 60 percent for stage-2 and 47 percent for stage-3 participants.

Based on the results of the present study, average spatio-temporal gait parameters, as well as VMT and VMG, are highly reliable and reproducible. Gait variability measures especially the COV of step length, COV SrT, COV Swt demonstrated high relative reliability and moderate absolute reliability. The measures of COP displacements and COV foot drifts showed wide
ranges of 95% confidence intervals for ICC values and higher MDC % values, thus demonstrating low test-retest reliability. Based on the findings of this research study, measures of average spatio-temporal gait parameters, VMT and VMG task measures are highly reproducible and recommended for evaluating DT performance in PD. Few of the measures for gait variability such as COV step length, stride time as well as swing time also demonstrated high relative reliability and recommended for quantifying DT-walking performance in PD. Because of the large confidence intervals, high sample variability and smaller than suggested sample size, Clinicians should be cautious while quantifying cop-displacements and variability in foot drifts in individuals with PD.
6.2: Construct validity

6.2.1: Discriminant Validity

Our results were consistent with the findings of Fernandes et al., 2015 (152) which reported a significant increase in COP-displacements during standing while performing a verbal fluency task as compared to stand only task. However, standing balance performance was only evaluated on a normal fixed surface which has limited balance cost in mild to moderate PD. Our study further extends the DT-balance paradigm by evaluating standing balance on a compliant sponge surface. Due to increased physical demands, participants have to concentrate simultaneously on maintaining standing balance on the sponge as well as perform the concurrent cognitive task during DT-standing balance activity. However, it should be noted that in the study of Fernandes et al., 2015 (152) performance of the verbal fluency task was not obtained during sitting as well as standing on a fixed surface (DT). Therefore, it is unclear if DT was being performed. The results of the present study show that during DT-standing balance conditions, PD participant’s exhibit increased COP-sway as compared to stand only on the sponge surface.

Limited information is available on evaluating DT-standing balance on sponge surface for PD patients. Results of our study are similar to the findings of Szturm et al., 2015 (72) which compared ST and DT-standing balance on a sponge for thirty healthy older adults (median age = 64). This research reported a significant increase in the RMS values (A-P as well as M-L) during standing on the sponge while performing similar VMT as well as VMG tasks as compared to stand only task in the healthy old age sample.
A number of studies have examined the effect of DT-walking on various spatial as well as temporal gait parameters in individuals with PD. The majority of these studies have been conducted over the ground and used a 5-meter GAITRite instrumented walkway for analyzing gait variables. Important to note that cognitive task performed during walking were restricted to a few meters (distance) and few seconds (time) consisting of task like counting backward or naming objects, animals (verbal fluency) etc. All these studies show a significant decrease in gait speed and increase in gait variability during the DT-walking condition as compared to walk only in PD patients (89,114,118,120,130,135,137).

The present study used a treadmill instrumented with pressure mapping system which controls for speed effect on gait variability measures. Most importantly treadmill does not allow participants to stop and thus to minimize the dual-task requirements. The treadmill-based system can easily record up to 30 or more consecutive steps (for a one-minute walking task) and cognitive tasks were performed simultaneously for 45-60 seconds. Thus, CGBRS provides a robust and objective evaluation of the cognitive performance and their actual impact on gait performance in PD participants. Results of our study are consistent with the findings of Szturm et al., 2017 (138) which reported significant reduction in average step length, swing time, stride time and increased gait variability during DT-walking as compared to walk only. This study was conducted on twenty-five healthy old age participants (median age = 64) and all walking tests were performed at a constant gait speed controlled by a treadmill. As discussed earlier increased gait variability is regarded as a critical indicator of unstable gait, reduced automaticity and increased risk of falls (149,154–156).

The visuomotor tracking (VMT) and visuomotor gaming (VMG) tasks used in this study require participants to actively rotate their heads in order to track (VMT) or interact (VMG) with
moving objects on a computer screen. Many different types of similar head pointing movements and gaze fixations occur during our daily activities such as locating vehicles while crossing road, walking while locating things in a shop etc. Most of the studies that examined DT-standing balance and DT-walking in PPD have used cognitive tasks such as– backward digit span, verbal fluency, auditory Stroop. The visuomotor tracking task in the present study requires visual vigilance and foveation of the moving targets to maintain their overlap. The present study has shown a significant reduction in most VMT task performance measures during DT-standing balance and DT-walking as compared to the sitting condition. The visuomotor gaming task challenges the critical aspects of the executive –cognitive functions like cognitive inhibition and spatial processing for interacting with the target object. As the physical load was increased, PPD showed a significant impact on the majority of the VMG task performance measures.

Bartmann et al., 2013 (157) compared text-comprehension, phoneme counting (number of times a word is repeated) and serial 7 subtraction task performance while walking over-ground on a 9-meter walkway and sitting (ST) condition in eighteen individuals with PD (stage -1 to 2, H-Y scale). All participants exhibited a significant reduction in the cognitive task performance during DT-walking as compared to the sitting task. The present study extends the previous DT walking research studies to include cognitive tasks that specifically challenge critical aspects of visuomotor as well as visuospatial ECF required for safe mobility behavior. Results of the present study were consistent Szturm et al., 2015 (72) and Szturm et al., 2017 (138), which showed a significant reduction in both visuomotor tracking (VMT) and visuomotor gaming (VMG) task performance during DT-standing balance and DT-walking conditions as compared to sitting (ST) in PPD. To our knowledge, no other study has examined the effect of sponge standing condition on concurrent cognitive task performance in PD patients.
Wollesen et al., 2016 (158) postulated various theoretical models to explain motor and cognitive interaction during DT performance, especially in the older population. Limited resource hypothesis explains that a common pool of cognitive resources in multiple brain regions are affected in the older population. If the dual-task load is greater than the available resources, there is a decline in either motor or cognitive or both tasks. The cross-domain competition model further explains the limited resource model and states that both motor and cognitive task's challenge the same brain resources (e.g., attentional resources) and increased demands on one task, for example, increased balance cost will subsequently cause a decrease in the cognitive performance during DT condition or vice versa. The task prioritization model explains the phenomenon observed during DT conditions where one task is often prioritized over the other like frail elderly participants prioritize motor tasks over the cognitive tasks. The cross-domain competition model is the most relevant explanation for the results of our study. In order to maintain a safe standing balance on the sponge surface and a constant gait speed on the treadmill, individuals with PD exhibit over-dependency on attentional resources of brain. The present study indicates that PPD had considerable difficulty maintaining the cognitive performance while simultaneously managing the increased balance cost and gait speed on the treadmill.

Various performance measures examined by the CGBRS presented the nature and influence of DT-interference in PD population as compared to the single task conditions. This establishes CGBRS as a sensitive and effective tool for discriminating the single task and dual-task performance in PD population.
6.2.2: Convergent Validity

A non–significant correlation between the DT performance measures and total score for the UPDRS-3 (motor examination part) indicated poor to no convergent validity of the CGBRS. These clinical findings are in line with the previous studies which examined the correlation between spatio-temporal gait parameters and UPDRS-3 during walk only conditions (159–161). The UPDRS questionnaire, though the most commonly used scale, has only one - question number 29 and 30 where gait performance and postural stability is examined for individuals with PD. All other questions are restricted to speech, tremors, rigidity, as well as hand and leg agility. These questions provide limited information about examining the critical aspects of standing balance and walking requirements in the PD population, especially in the DT conditions. As described in Brusse et al., 2005, clinicians should separately examine the gait performance by evaluating the critical spatio-temporal gait parameters in patients with PD. This research study further extends the findings by associating DT-standing balance and DT-walking parameters, but as expected results are inclined towards the poor convergence with UPDRS-3.

These findings clearly indicate that UPDRS-3 and CGBRS results examine distinct components and features of mobility impairments in PD population. While the CGBRS quantitatively examine the COP excursions, spatio-temporal gait parameters, and executive-cognitive function during the DT activities. The UPDRS is a qualitative questionnaire-based tool that primarily evaluates rigidity, tremors, general hand and leg movements PD participants.
6.3: DT-Walking in stage-2 and stage 3 participants with PD

Findings of the present study showed that the majority of the gait variables were different between stage-2 and stage-3 participants. These findings are consistent with results of Hass et al., 2012 (21) which compared ST gait performance for both stage-2 and stage-3 PPD using a GAITRite instrumented walkway. A significant reduction of step length, swing time (% of total cycle) and increased step time, stance time (% cycle) as well as double-support time were observed for stage 3 PPD as compared to stage-2 individuals with PD. Another study, Schlachetzki et al., 2017 (78) compared over-ground normal walking between stage-2 and stage-3 PPD using inertial sensors. This study showed a significant decrease in gait speed, step length and foot clearance in stage -3 participants as compared to the stage-2 PPD.

Limited information is available on the difference in DT-walking performance between stage-2 and stage-3 PD patients. As compared to stage-2 participants, stage-3 participants walked with significantly reduced step lengths and exhibited higher variability or COV values for SL, SwT and drifts in M-L directions during DT-walking on the treadmill. Furthermore, both stage-2 and stage-3 participants exhibited significant DT-interference on the majority of the gait and cognitive task performance measures as compared to ST condition. During DT-walking condition (VMT and VMG both) stage-2 participants showed a significant increase in COV swing time as compared walk only task while no such effect was noticed for stage-3 participants. Additionally, during the DT-walking condition, stage-3 participants showed significantly higher COV SwT and decreased VMT as well as VMG task performance as compared to the stage-2 participants. This certainly indicates towards the task-prioritization model where stage-3 PPD are
concentrating more towards maintaining a stable walking pattern and as a result, less attention is assigned towards the cognitive task performance. On the contrary, stage-2 PPD exhibits a cross-domain competition where increased cognitive load causes a significant reduction in gait performance i.e. increased the SwT variability. Some studies have also associated increased PD severity (H-Y scale) with increased gait variability (159) which is a critical indicator of reduced gait stability and increase risk of falls in stage-3 PPD. Further extending the paradigm of discriminant validity, CGBRS proves to be a sensitive tool for distinguishing stage-2 and stage-3 (H-Y scale) individuals with PD, during both single and dual-task conditions.
Chapter 7. Conclusion, strength, limitations and future implications

7.1: Conclusion

The computer game-based rehabilitation system or CGBRS proves to be a reliable, valid and sensitive platform for examining the standing balance, gait, visuomotor tracking (VMT) and visuomotor gaming (VMG) task performance during both single as well as DT-conditions in PD population. Majority of the average gait parameters, VMT and VMG task performance measures demonstrated moderate to good test-retest reliability and were highly sensitive towards the DT-conditions. These measures are highly reproducible and appropriate for examining dual-task performance in PD population. The majority of standing balance measures and gait variability parameters exhibited very high sensitivity for differentiating the single and DT-performance in PPD, but they also demonstrated a low test-retest reliability. Thus, clinicians must be careful while using these performance measures and should opt for an adequate sample size and low sample variability during DT evaluations in PD. Participants included in the present study represented a wider range of PD severity. This contributed towards higher group variability, higher MDC values and a low absolute reliability for few performance measures.

Findings of this study revealed a significant rise in COP-displacement during DT-standing task as compared to the normal standing on a sponge, which increases the risk of falls in PD. During DT-walking condition, PPD showed a significant reduction in swing time, stride time and increased gait variability as compared to walk only task. These findings successfully establish the discriminant validity of CGBRS for distinguishing single and dual-task
performance in PD participants. Moreover, CGBRS is also capable of distinguishing between stage-2 and stage-3 (H-Y scale) PD individuals during walk only and DT-walking conditions. The CGBRS provides a detailed quantitative assessment of standing balance, gait as well as executive-cognitive performance during single as well as DT conditions, thus a low convergence with UPDRS was predictable.

There is a need to develop a reliable, valid and accurate system that can be used to test the effectiveness of DT interventions and assess the risk of falls in PD population. Computer application software used in the present study can examine a large variety of visuomotor and visuo-spatial executive-cognitive functions while simultaneously walking on a treadmill or standing on sponge surface. An important aspect of CGBRS is that it is an inexpensive, accurate, user-friendly rehabilitation platform that has a potential to be used in various recreational or community center to assess fall risk in PD population.
7.2: **Strengths of the research study**

1. Majority of the studies have examined standing balance on a firm surface for studying the effect of DT on balance for participants with PD. All our testing has been done on a compliant surface, i.e. sponge, which effectively challenge balance for stage -2 and stage-3 individuals with PD. This aspect of our testing can be used to effectively emulate the CTSIB, which evaluate standing balance during eyes open/closed on firm and compliant surface.

2. Many studies have examined DT-walking in PD patients and most have used GAITRite, foot pressure insoles, and video camera analysis for quantifying spatio-temporal gait parameters. These instruments can only test up to 4-6 consecutive steps, which even limit the secondary cognitive task to short distance and time. Studies have shown the importance of a continuous walking protocol and examining at least 30 steps for reliable estimation of gait variability in PD population. In CGBRS, treadmill-based walking trials ensure continuous walking protocol and pressure mapping system can provide detailed analyses of at least 30 to 40 steps (during a one-minute trial).

3. Computer gaming application, NFE is capable of providing us a detailed analysis of VMT and VMG task performance. Total residual errors, as well as amplitude consistency, are used to evaluate the VMT task, while response times, movement variance and success rates are examined for VMG task performance. Majority of the research studies have used simple cognitive tests like Stroop, backward counting etc. and report only about the objective measures assessing the performance of the secondary
cognitive task. Our analysis examines the critical aspects of visual attention, navigation, tracking etc. that are required for maintaining safe mobility and balance in PD patients.

4. Apparatus used in this research study which consists of a treadmill and computer gaming system is affordable and can be easily be installed in physiotherapy clinics as well as community rehabilitation centers for reliable analysis of DT-balance, DT-walking and evaluating the fall risk in PD population.
7.3: Study limitations

1. The narrow width of the treadmill belt put some restriction on the natural gait in PD. Thus, treadmill walking does not completely replicate the natural over-ground walking behaviors.

2. All participants were tested in “ON-state” of their medication regime, and not in “Off-state” of their medication. The majority of the participants does spend most of their day in “On-state”, but it still does not represent the whole spectrum of PD. Thus, results of our study only applicable during for the ‘ON-state’ of medication in PD.

3. Results of our study are only applicable for individual at stage-2 (mild) and stage-3 (moderate) PD. Stage-1 (unilateral symptoms) or very severely affected stage 4 or 5 individuals with PD were not included in this research study.

4. The sample size of thirty-five participants was estimated for this study. We were only able to recruit 26 participants with PD, thus increasing the risk of type-2 error in the clinical findings of this study.
7.4: Future implications

1. Future studies will involve detailed analysis of feasibility and a randomized control trial to compare the effect of a computer game based dual-task training in PD population. Many recent studies have used virtual reality and other forms of digital media along with treadmill training to improve DT-walking in individuals with PD. Our system can effectively operate many commercially available fun and interactive computer games, which can be used to challenge critical aspects of visuomotor and visuo-spatial executive cognitive functions in PPD. A training protocol will be established to train both DT-walking as well as DT-standing balance, and CGBRS will be helpful in evaluating the results.

2. Future studies should aim to establish the test-retest reliability for the measures of gait variability and COP-displacements during DT conditions in the PD population. They should opt for a stronger sample size and low sample variability.

3. Future studies can compare effect over-ground and treadmill-based DT-training protocols to study improvements in overall dual-task walking in participants with PD.

4. Future studies can examine the critical aspects of DT-interference and type of DT-interference effects that are associated with the prediction of falls and institutionalization in PD.

5. Future studies can be done to compare the single task and DT performance for PD patients and healthy controls using this system to evaluate balance, gait and cognitive performance.
6. Future studies can further examine the mechanical effect of head movements on various aspects of standing balance and gait in individuals with PD.
References


2. Parkinson’s Disease | UCB [Internet]. Available from: http://www.ucb-canada.ca/en/Patients/Conditions/Parkinson-s-Disease


11. Cicchetti F, Drouin-Ouellet J, Gross RE. Environmental toxins and Parkinson’s disease:


Evaluation of a Computer Game Based Rehabilitation System for assessment of balance and gait impairments in individuals with Parkinson’s disease.


Aug 7 [cited 2018 Jan 28];7:152. Available from:

http://journal.frontiersin.org/Article/10.3389/fnagi.2015.00152/abstract

http://journals.sagepub.com/doi/10.1177/1545968314567150


45. Difrancesco-donoghue J, Jung M, Apoznanski T, Werner WG. The Reliability of the
Sensory Organization Test in Parkinson’s Disease to Identify Fall Risk. 2016;2(5):39–43.


59. Ribas CG, Alves da Silva L, Corrêa MR, Teive HG, Valderramas S. Effectiveness of


65. Scalzo PL, Nova IC, Perracini MR, Sacramento DRC, Cardoso F, Ferraz HB, et al. Validation of the Brazilian version of the berg balance scale for patients with Parkinson’s

dysfunction in Parkinson’s disease: The role of posturography in developing a

67. Bekkers EMJ, Dijkstra BW, Dockx K, Heremans E, Verschueren SMP, Nieuwboer A.
Clinical balance scales indicate worse postural control in people with Parkinson’s disease
who exhibit freezing of gait compared to those who do not: A meta-analysis. Gait Posture
[Internet]. 2017;56:134–40. Available from:
http://dx.doi.org/10.1016/j.gaitpost.2017.05.009

68. Johnson L, James I, Rodrigues J, Stell R, Thickbroom G, Mastaglia F. Clinical and
6.


70. Da Silva BA, Faria CDCM, Santos MP, Swarowsky A. Assessing timed up and go in
Parkinson’s disease: Reliability and validity of timed up and go assessment of

71. Kerr GK, Worringham CJ, Cole MH, Lacherez PF, Wood JM, Silburn PA. Predictors of

72. Szturm T, Sakhalkar V, Boreskie S, Marotta JJ, Wu C, Kanitkar A. Integrated testing of
standing balance and cognition: Test-retest reliability and construct validity. Gait Posture
[Internet]. 2015;41(1):146–52. Available from:


87. Bezdicek O, Růžička F, Fendrych Mazancova A, Roth J, Dušek P, Mueller K, et al. Frontal Assessment Battery in Parkinson’s Disease: Validity and Morphological...


Evaluation of a Computer Game Based Rehabilitation System for assessment of balance and gait impairments in individuals with Parkinson’s disease.


123. Cole MH, Sweeney M, Conway ZJ, Blackmore T, Silburn PA. Imposed Faster and Slower
http://dx.doi.org/10.1016/j.apmr.2016.11.008

http://dx.doi.org/10.1016/j.gaitpost.2013.02.004


146. Strouwen C, Molenaar EALM, Keus SHJ, Müinks L, Bloem BR, Nieuwboer A. Test-Retest Reliability of Dual-Task Outcome Measures in People With Parkinson Disease. [cited 2018 Jun 27]; Available from: https://watermark.silverchair.com/ptj1276.pdf?token=AQECAHi208BE49Ooan9khhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAaEwggGdBgkqhkiG9w0BBwagggGOMIIBigIBADCCAYMGCSqGSIb3DQEHAeBglghkgBZQMEAS4wEQQM6Pf4GWF9ghZ3ZSfhAgEQgIBVA6fdpGaSaL5KeA-vciHN-aANUXK392pV0XW90iLy1QFrPaN81LbgRJZvqMtzDA0Vws65VfwpVKHOEsYFpJVK3txJWBB99qQofy10Ev1J9-uDdVQHCTTVdLk_XW4KYveL8fSyguQNy8b8UgLVRd_6M1vRcoLo56jsezqolN5yeQVvmNM4hqPEr1wdG-MEU-110s-Xx-mwXDcp-L7ovY3tUOkpMIPgFHG7QjcNA7e6SFobCY9x8aTdsHMnFGj7foKNNh1p70cqMyYY19HOYZ1LEppDG-brJGkIpFOb0WHIGQm9VYOcfNcoagXBYMF9btHMtq7h-19Xfq0Xb3j0tXidgAoFP13udVL4YY2UNjttxcwuA1a4nRTZ5IPXInCvzspVzhCjBsOjDz


160. Charness AL. Correlations of Balance and Gait Measures with the UPDRS and with Each Other. 2013;

